Nasa CR 65379

FINAL REPORT

for

Spaceborne Gas Chromatograph

24 February 1964 - 1 May 1966

[redacted]

Contract No. NAS 9-2518

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
Houston, Texas

Prepared by

MELPAR, INC.
7700 Arlington Boulevard
Falls Church, Virginia 22046

April 1966

FINAL REPORT

FOR

SPACEBORNE GAS CHROMATOGRAPH

24 February 1964 - 1 May 1966

Contract No. NAS 9-2518

Prepared for

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas

Prepared by

Melpar, Inc.
7700 Arlington Boulevard
Falls Church, Virginia

April 1966

N66 2837

ABSTRACT

This final report summarizes the work carried out for NASA, Houston, on the fabrication of flight qualified gas chromatography detectors under contract NAS 9-2518. In the development of the gas chromatography system, innovations were made in column and detector technology, sample injection techniques, and basic electronics. The systems as delivered potentially can separate and detect approximately 75 compounds at detection sensitivity levels approaching a few parts per million. The gas chromatography detector is completely automated and will function on a repetitive analytical cycle without attention for a minimum of 15 days.

Author

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT'D.)

LIST OF TABLES

1. INTRODUCTION

The Spaceborne Gas Chromatograph has been designed to analyze a wide variety of gases and vapors at concentrations down to the part-per-million level. This instrument is shown in figure 1. A titanium sphere for helium carrier gas storage and a 2-stage pressure regulator are mounted at the rear of the instrument. The bulk of the components are mounted within the supporting framework. A space exhaust port at the lower right of the front panel is connected to space vacuum so that spent helium carrier gas and sample may be evacuated. The "From Suit" and "From Cabin" ports are the sources of the two samples for this instrument. The "To Suit" port is used to circulate one sample while the other is being analyzed. The switch is used for preheat and operation of the instrument. The sample selector valve is used to analyze either cabin or suit atmospheres. In the "Auto" position, the cabin and suit samples are sequentially selected. The helium fill port is utilized to load the helium sphere with 6000 psig helium prior to flight. A calibration button is provided to check proper operation. The electrical connector at the lower left is utilized for incoming power, two telemetry output channels, and an oxygen readout meter.

This gas chromatographic instrument basically consists of a programmer, sample selector valve, injection valve, column selector valves, three partitioning columns, three cross-section ionization detectors and an amplifier assembly. The programmer controls the valve operations and sequentially selects the appropriate detector. The sample selector valve allows either cabin or suit sample to circulate through the injection

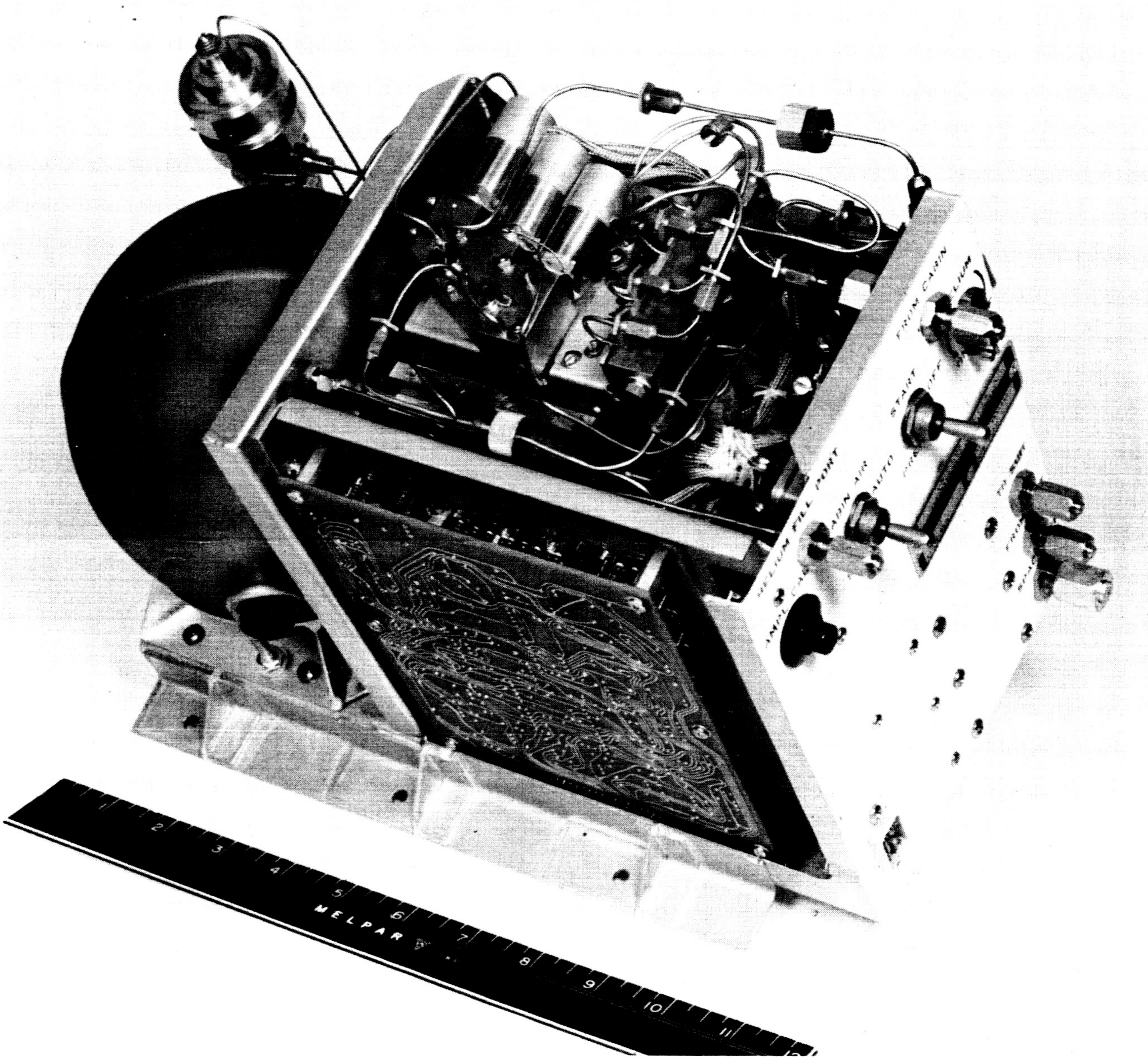


Figure 1. Side View of Apollo Gas Chromatography Analyzer System

valve. The injection valve injects a known volume of sample into the column system at periodic intervals. The column selector valves are used to prevent the flow of helium and sample through two of the three columns when they are not in use.

The columns consist of: (1) Molecular sieve for permanent gas separation; (2) Carbowax-Amine coated Teflon for the separation of NH_3, CO_2, H_2O, alcohols, and certain other organic compounds; (3) Carbowax-coated chromosorb for separating the bulk of the probable organic compounds. The cross-section detector housing includes three chambers, one for each of the columns. The amplifier assembly automatically maintains the baseline at the zero level, except when a compound is eluted, and provides automatic attenuation of compound peaks present in concentrations greater than 50 to 100 ppm.

This instrument, like other gas chromatographic instruments, relies on the elution times of sample peaks for their qualitative identification. The certainty of correct identification is greatly enhanced through the use of two different liquid-phase partitioning columns which provide markedly different elution times. This instrument is capable of quantitatively analyzing samples containing as much as 100% oxygen and as little as a few ppm of organic contaminants, thus providing a very large dynamic range. Furthermore, every effort has been made to provide completely automatic, reliable operation under the stresses encountered by space flight instruments. The delivery status of the six units constructed under this contract is shown in table 1.

TABLE 1

DELIVERY STATUS-GCAS

Unit No.	Delivered	Remarks
S/N 1 Prototype Model	1-21-65 to NASA, Houston	Ret'd by NAA on 1-5-66 for Repair. At Melpar for NAS 9-4867 Development of Operations Plan
S/N 2 Qualification Test Model	4-18-66 to NASA, Houston	Delivered after completion of environmental testing
S/N 3 Qualification Test Model	1-11-66 to NAA	Loaned to NAA in lieu of return of S/N 1. Environmental tests complete.
S/N 4 Flight Model	6-2-65 to NASA, Houston 7-2-65 to NASA, Houston 3-14-66 to NASA, NAA	Ret'd to Melpar 6-28-65 Ret'd to Melpar 2-1-66 for retrofit
S/N 5 Flight Model	9-16-65 to NASA, Houston 11-2-65 to NASA, Houston	Ret'd to Melpar 10-26-65
S/N 6 Flight Model	1-28-66 to NASA, Houston	

2. COLUMNS AND DETECTORS

The first column was designed to separate the permanent gases. An 8-foot column packed with 90/100 mesh molecular sieve 5A was found to be suitable for this purpose. This column was conditioned at 175°C with a helium flow of 12 ml/min for 6 hours before use. Since the retention of permanent gases on a molecular sieve column is highly dependent on the quantity of adsorbed water, various methods of preventing water adsorption were tested. The most satisfactory method of trapping moisture was found to be by the use of a short tube containing magnesium perchlorate granules. It was found that a 2.5-inch length of 0.093 inch I.D. tube filled with magnesium perchlorate granules was capable of adsorbing up to 20 mg water. This is greater than the expected quantity of injected water after a month of continuous operations.

The second column was designed to separate carbon dioxide, ammonia, and water as well as many of the possible trace contaminants. All of these major components are highly adsorbent. Consequently, it was decided to utilize Teflon solid support material in order to minimize adsorption problems. In our laboratories, the most efficient and reproducible columns were prepared when Teflon 6 was sieved to 40/60 mesh size and coated by the usual liquid phase-solvent evaporation technique. This is essentially the same technique used by Kirkland[1].

The choice of liquid phases for the second column was governed by the need to separate carbon dioxide from air. A large variety of liquid

---

1. Messner, A.E., Rosie, D.M., and Argabright, P.A., Anal. Chem. 31, 230-232, (1959).

phases having a high degree of basicity were tested for this purpose. One of the major problems encountered was excessive tailing of the carbon dioxide peak. This problem was aggravated either by increasing the column basicity or decreasing the column polarity. The final liquid phase chosen was a mixture of 60 parts Amine 220 with 40 parts Carbowax 600. This combination allowed symmetrical elution of carbon dioxide while still maintaining adequate separation. The liquid phase was coated on Teflon 6 (10% w/w) and the resulting packing was filled into a 12-ft column. This column was conditioned at 100°C for 8 hours with a helium flow rate of 12 ml/min.

The third column was designed to separate high- and medium-volatility trace contaminants. Carbowax 20M was chosen as the liquid phase for this column because of its high degree of stability and polarity. Since this liquid phase is considerably more polar than the liquid phase used for column 2, the retention characteristics of this column were considerably different. This is expected to simplify the identification of unknown trace contaminants.

It was desired to use chromosorb as the solid support for this column because of its high degree of efficiency. The major disadvantage of chromosorb is its tendency to adsorb highly polar compounds. Consequently, a brief study was made to determine the relative adsorption properties of various types of chromosorb. Chromosorbs W, P, and G were coated with Carbowax 20M (10% w/w), placed in 12-ft by 0.062-inch I.D. columns and conditioned at 150°C for 6 hours with a 15 ml/min helium flow. These columns were then tested with propanol to determine the retention characteristics and efficiency. All tests were made at 150°F with a cross-section ionization detection and syringe injections. The results of these tests are shown in table 2.

TABLE 2

COMPARISON OF CHROMOSORB W, P, AND G

	Chromosorb W	Chromosorb P	Chromosorb G
Mesh size	90 - 100	100 - 120	80 - 100
Chemical treatment	Acid base washed, HDMS treated		Acid washed, DMCS treated
Flow rate	13.1 ml/min	9.1 ml/min	12 ml/min
Retention time propanol	7.4	12.6	26.8
Efficiency of propanol (theoretical plates)	1350	1600	2000

These results indicate that chromosorb G exhibits greater retention than chromosorb P, whereas chromosorb W has the least retention. Efficiency also differs in the same order with chromosorb G being the most efficient solid support. The results shown in table 2 do not indicate a clear superiority of any solid support, since efficiency is merely being traded for speed. This same trend could have been obtained simply by using different column lengths for any of these solid supports.

The adsorption properties of these solid supports were tested by injecting different quantities of a 1% solution of methanol in propanol into each of these three columns. Peak heights obtained from a conventional cross-section ionization detector were measured. These results are shown in figure 2. The absolute response values are unimportant in this case, since the flow rates and peak widths were slightly different for each column. The points at which the response curves intersect the zero response line are of interest, however, since this is a measure of the relative adsorption capacity of each column. With the chromosorb W column, methanol concentrations of 2 x 10^{-5} ml could not be detected. The chromosorb P column exhibited less adsorption than chromosorb W, but it is apparent that less than 1 x 10^{-5} ml methanol would be very difficult to detect. The chromosorb G response curve intersected the zero axis. This indicates that chromosorb G exhibited little or no methanol adsorption at the concentration levels tested. Later investigations showed that adsorption of methanol by chromosorb G columns did not become excessive unless quantities below 1 x 10^{-7}g were injected. The column used in all further work consisted of a 15-ft tube packed with 10% w/w Carbowax 20M on chromosorb G.

The most important detector requirements for this application are wide dynamic range and high reliability. Suitable detectors would include thermal conductivity,[1] quench,[2] helium ionization,[3] and cross-section ionization detectors.[4] Thermal conductivity detectors were considered to be too fragile and temperature sensitive for the rigors

---

1. See footnote, page 10.
2. Lovelock, J.E., <u>Anal. Chem.</u>, <u>33</u>, 162-178, (1961).
3. Berry, R., <u>Nature</u>, 188, 578 (1960).
4. Pompeo, D.J. and J.W. Otvos, U.S. Patent 2,741,710 (1953).

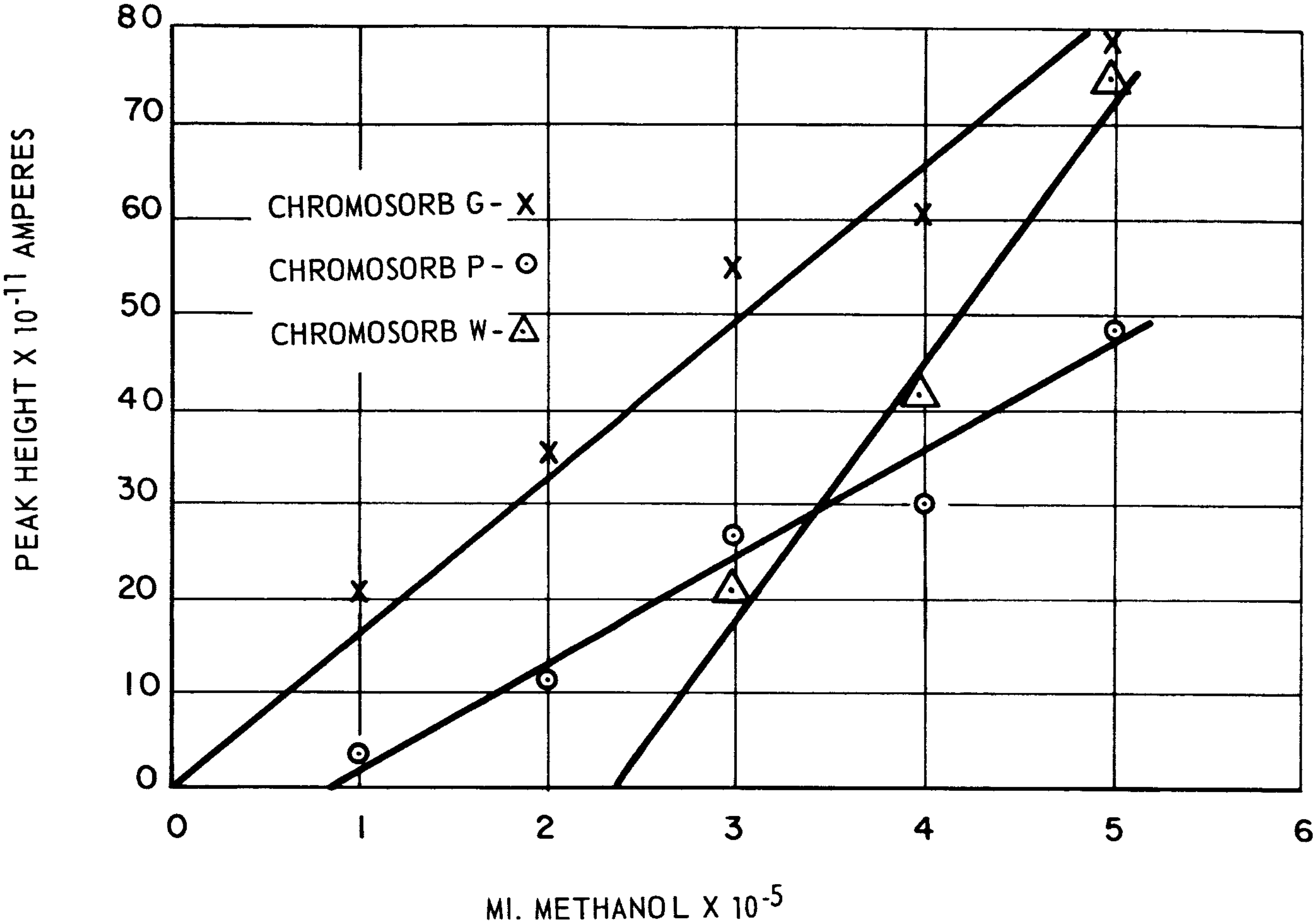


Figure 2. Effect of Solid Support Material

of space flight. Quench and helium ionization detectors are extremely sensitive but require extremely well regulated power supplies and are susceptible to a great many environmental conditions. Previous experience has indicated that the cross-section ionization detector is extremely rugged and reliable. Although it is less sensitive than other detectors, sensitivity is believed to be adequate for this application.

The cross-section ionization detector has been extensively investigated by Lovelock et al.[5] It is basically a parallel plate diode whose ionization energy usually is supplied by tritium foil. When helium is used as the carrier gas, all compounds produce an increase in current. The construction of the detector used in this study is shown in figure 3. In figure 3 all three detector chambers are enclosed in the same case, thus leading to a considerable saving in space and weight. Preliminary investigations supported Lovelock's[5] conclusion that sensitivity is increased as the detector volume is decreased.

Extremely small detector volumes, however, were found to be undesirable for this particular application because of a number of reasons. Very small detectors produce less output current than larger detectors therefore requiring higher impedance amplifiers. Very high impedance amplifiers compatible with space-flights requirements are difficult to obtain.

Very small detectors tend to reach their maximum current output at smaller sample concentrations. This requires smaller sample injections

---

5. Lovelock, J.E., Shoemake, G.R., and Zlatkis, A., Anal. Chem., 35, 460 (1963).

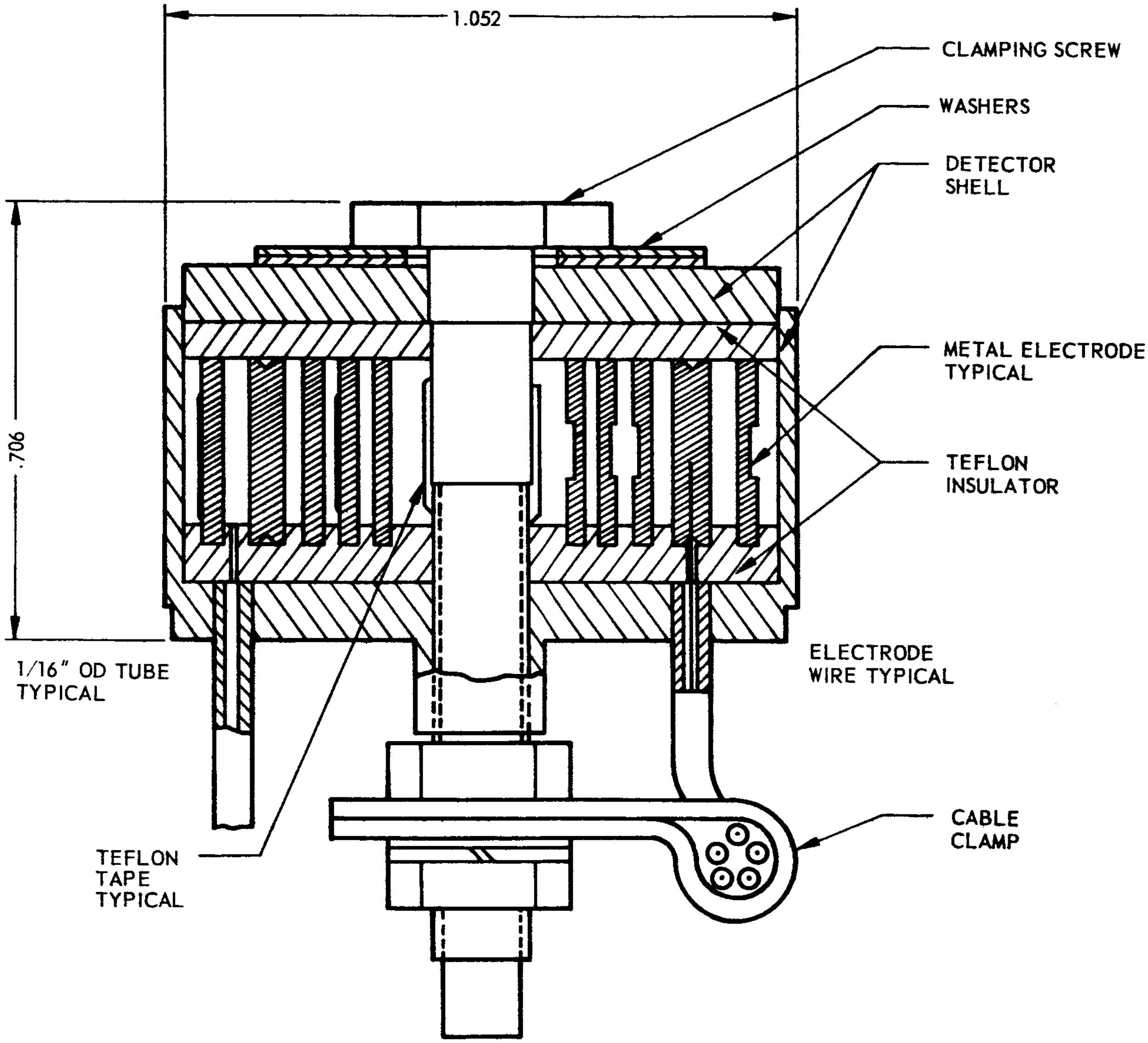


Figure 3. Three Chamber Cross-Section Ionization Detector

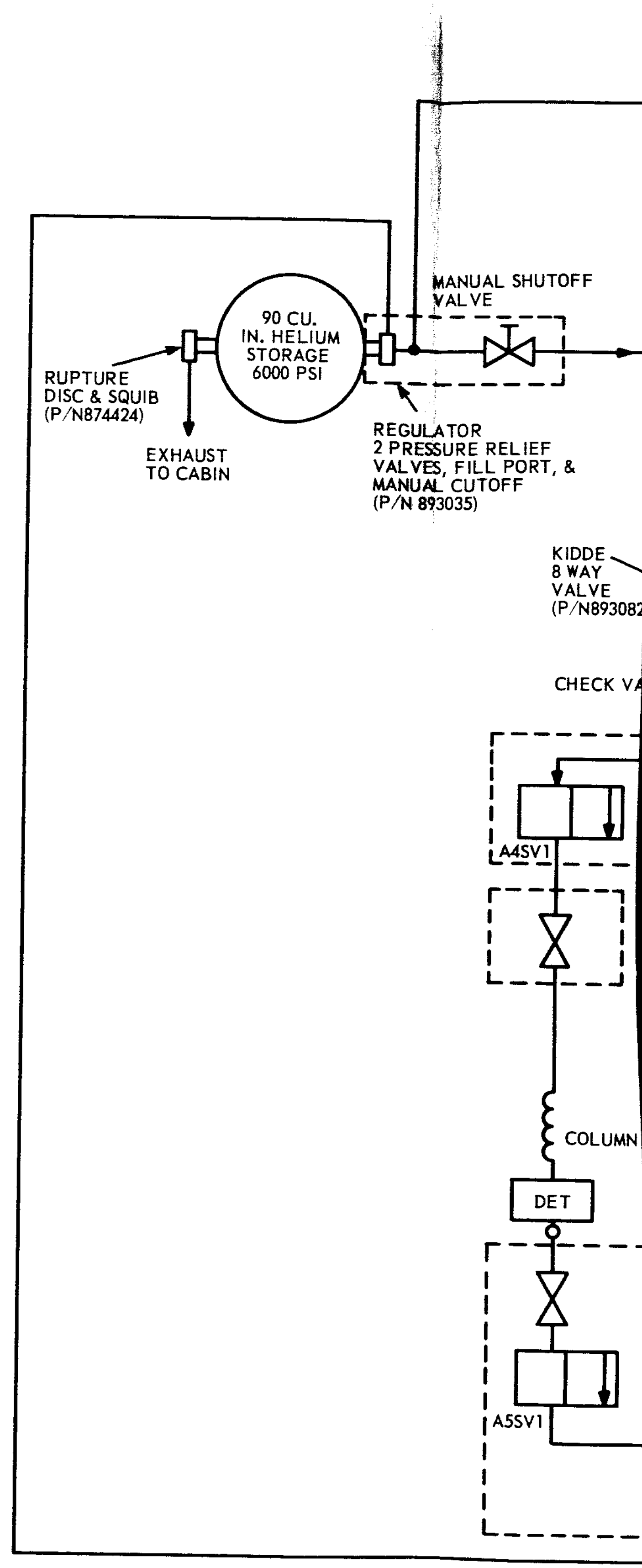
if large sample concentrations also must be monitored. The smaller sample injection now tends to magnify the effect of column adsorption and column bleeding. Thus, the actual detector chamber dimensions shown in figure 3 represent a compromise between the good sensitivity of small chambers and the large sample capacity of large chambers. The first chamber, which detects the permanent gases, must handle concentrations up to 100%. Consequently, it is necessarily larger than the other chambers. Chamber 2, which detects components eluted by column 2, must handle up to 10% carbon dioxide. It, therefore, has an intermediate volume. Chamber 3 need detect only the trace contaminants. Consequently, this chamber was made as small as feasible.

3. MECHANICAL COMPONENTS

3.1 Overall Gas System Layout

A schematic diagram of the gas system assembly is shown in figure 4, and a gas manifold diagram is shown in figure 5. Each of the two sample source lines (upper right corner of figure 4) is supplied with a filter to remove particulate matter. The "From Cabin" line contains an emergency shutoff valve (A4SV4), which is closed by the pressure-sensing switch whenever the cabin pressure falls below 2.0 psia. This valve was necessary to prevent suit decompression in the event that cabin pressure was lost. The sample selector valve (1SV1) allows either the suit or cabin sample to flow into the injection valve system. The other sample is circulated through a needle valve to the "To Suit" port. The sample to be analyzed flows through a filter and a check valve to the injection valve. Depending upon the valve positions, this sample will flow through one of the 1-ml sample loops or the 0.2-ml sample loop to the metering device assembly. The sample is then allowed to flow out the space exhaust port.

The helium fill port (upper right corner of figure 4) is used in filling the helium storage bottle to 6000 psig. A rupture disc is provided to vent the contents of the storage bottle if the pressure exceeds 7000 psig. An electrically actuated squib is also provided so that this bottle may be emptied prior to reentry. A manual shutoff valve is provided in the pressure regulator so that this bottle may be filled well in advance of lift-off. The 2-stage pressure regulator is referenced to space vacuum and contains pressure relief valves to prevent accidental pressure buildup from rupturing any gas lines. This valve has been adjusted to deliver a



MANUAL SHUTOFF VALVE
90 CU. IN. HELIUM STORAGE 6000 PSI
RUPTURE DISC & SQUIB (P/N874424)
EXHAUST TO CABIN
REGULATOR 2 PRESSURE RELIEF VALVES, FILL PORT, & MANUAL CUTOFF (P/N 893035)
KIDDE 8 WAY VALVE
A4SV1
COLUMN
DET
A5SV1

19 ⓪

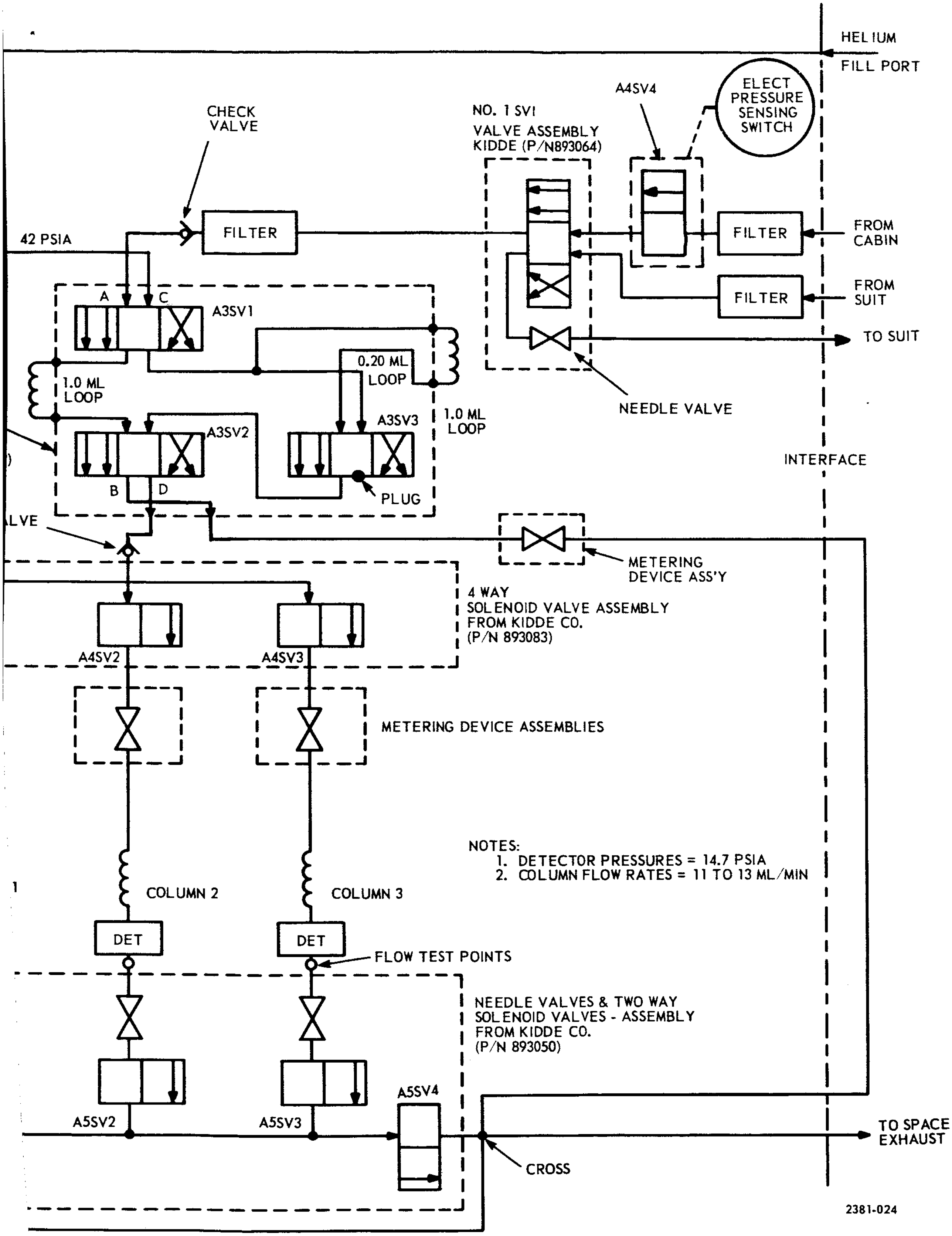
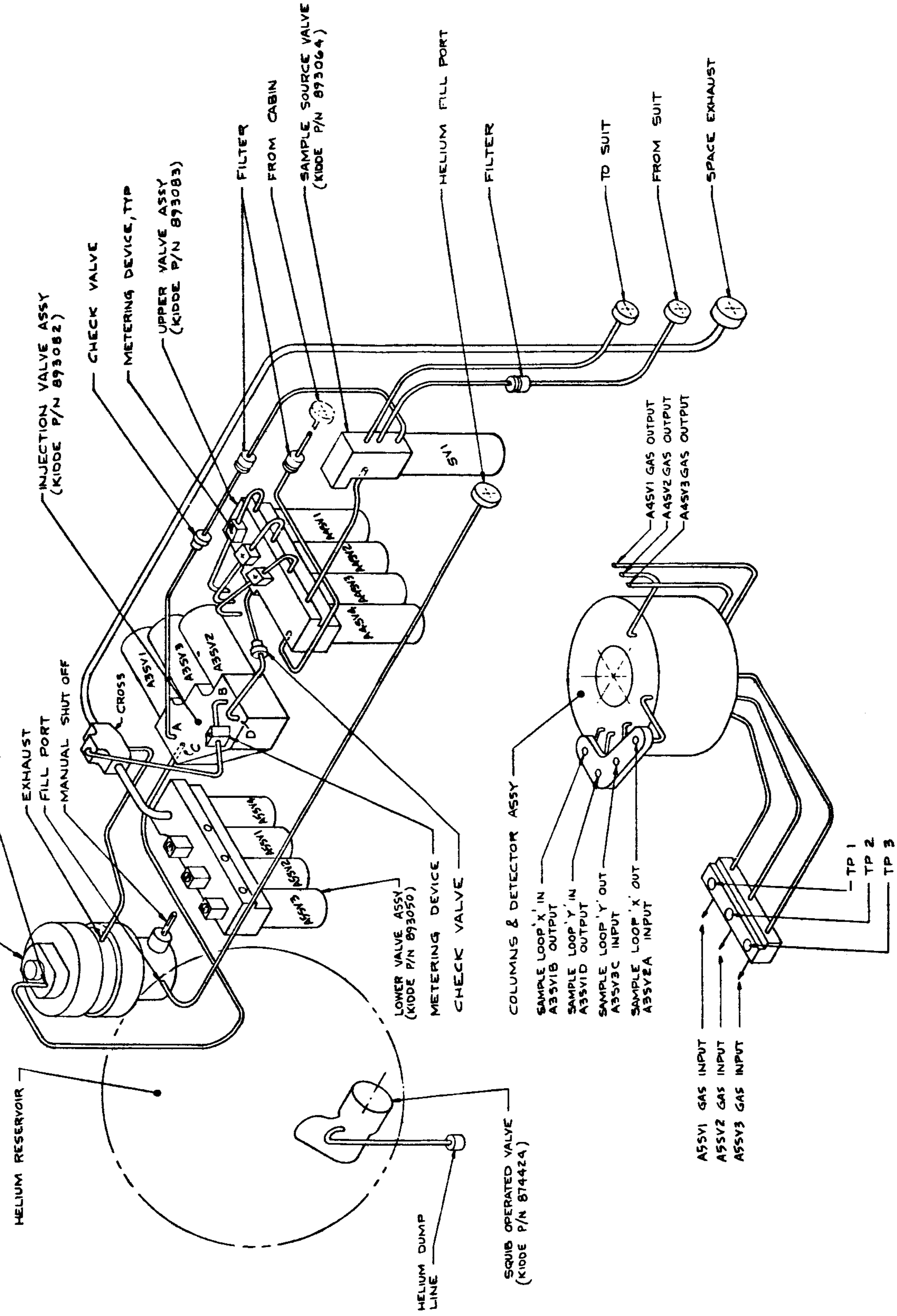


Figure 4. Gas System Diagram



REF: R448916
2381-023

Figure 5. Gas Manifold Diagram

constant 57 psia helium pressure to the system. The helium flows through the injection valve assembly and through a check valve to the column selector valves (A4SV1, A4SV2, and A4SV3). In most cases, only one valve is open so that helium will flow through only one column at a time. Each column is preceded by a metering device assembly to control the flow rate of 12 ml/min. Each column is connected to a separate detector chamber. The detectors are followed by individual needle valves which maintain the detector pressure at 14.7 psia when the system is in operation. The needle valves are followed by helium shutoff valves (A5SV1, A5SV2, and A5SV3). These valves always are in the same position as the corresponding column selector valves (A4SV1, A4SV2, and A4SV3) so that any column-detector assembly is either open at both ends or closed at both ends. An emergency shutoff valve (A5SV4) is used between the rear of the system and the space exhaust port to prevent deterioration of the system by the space vacuum when the system is turned off.

3.2 Valve Functions

The valve sequence is shown in figure 6. At 4.7 seconds after the instrument is turned on injection valve A3SV3 is crossed, cabin shutoff valve A4SV4 is opened, exhaust valve A5SV4 is opened, and both inlet and outlet valves for column 1 (A4SV1 and A5SV1) are opened. Inlet and outlet valves for column 3 would normally be open at this time, and injection valves A3SV1 and A3SV2 would normally be in the straight position. The sample selector valve 1SV1 would be in the same position as it was left when turned off. Under these conditions, the atmosphere sample is free to circulate through the 0.2-ml sample loop and out the space exhaust port.

GAS SYSTEM FUNCTIONS (PER COMPLETE CYCLE) FUNCTION	TIMING: CUMULATIVE TIME TIME ZERO ↓	TIMING: TIMED PULSES (SHOWN AS DASH LINES)		8 WAY INJECTION VALVES 1A3A2A3: TOP SV 1	BOTTOM SV 2	SAMP. SIZE SV 3
1 PURGE COL 1	4.6875 SECS.	t_1 — t_3 —				
2 LOAD 0.2 CC LOOP		t_4 —				
3	4.375 MIN.	t_1 —				
4		t_2 —				
5 INJECT 0.2 CC SAMPLE COLUMN 1 & LOAD 1 CC LOOP		t_3 —				
6 SHUT-OFF COL. 3		t_4 —				
7 INJECT 1 CC SAMPLE COL. 1	7.500 MIN.	t_3 —				
8 PURGE COL. 2	10.00 MIN.	t_1 — t_4 —				
9 INJECT 1 CC SAMPLE COL. 2	14.375 MIN.	t_1 — t_3 —				
10 PURGE COL. 3	45.00 MIN.	t_4 —				
11 INJECT 1.0 CC SAMPLE COL. 3	49.375 MIN.	t_1 — t_3 —				
12 SAMPLE SOURCE CHANGE (IN AUTO)		t_4 —				
↑ AT 80.000 MINUTES RETURN TO TIME 'ZERO'	80.000 MIN.					

NOTES

1 THIS VALVE MAY BE IN EIT

2 THIS VALVE POSITION IS CH
AND IS NEVER CHANGED BY

22 0

TOP COL. MANIFOLD VALVES 1A3A2A4					BOTTOM COL. MANIFOLD VALVES 1A3A2A5			
COL. 1 SV 1	COL. 2 SV 2	COL. 3 SV 3	CABIN SHUT-OFF SV 4		COL. 1 SV 1	COL. 2 SV 2	COL. 3 SV 3	EXHAUST SV 4
↓ ⊥	↓ ⊥	↓ ⊥	↓ ⊥		↓ ⊥	↓ ⊥	↓ ⊥	↓ ⊥
↓	⊥	↓	↓		↓	⊥	↓	↓
↓	⊥	↓	THIS VALVE IS CLOSED UPON POWER REMOVAL AND/OR LOW CABIN PRESSURE		↓	⊥	↓	THIS VALVE IS CLOSED UPON POWER REMOVAL
↓	⊥	↓			↓	⊥	↓	
↓	⊥	⊥			↓	⊥	↓	
↓	⊥	⊥			↓	⊥	↓	
↓	⊥	⊥			↓	⊥	⊥	
↓	⊥	⊥			↓	⊥	⊥	
↓	↓	⊥			↓	↓	⊥	
⊥	↓	⊥			⊥	↓	⊥	
⊥	↓	↓			⊥	↓	↓	
⊥	⊥	↓			⊥	⊥	↓	
⊥	⊥	↓			⊥	⊥	↓	

ER POSITION UPON POWER APPLICATION AT FUNCTION NO. 1.

ANGED AT FUNCTION NO. 12 BY THE PROGRAMMER CONTROL
ACTUATION OF THE "SUIT-AUTO-CABIN" SWITCH.

22

2

The helium will flow through sample loop A, through both columns 1 and 3, and out the space exhaust port. At 4.375 minutes the inlet and outlet valves for column 3 (A4SV3 and A5SV3) are closed, and injection valves A3SV1 and A3SV2 are placed in the cross position. The sample will now circulate through sample loop A. The 0.2-ml sample, which had been collected in the small sample loop, is forced out by the helium flow through column 1. The oxygen meter circuitry is utilized to quantitatively determine the oxygen peak eluted between 4.375 and 7.5 minutes.

At 7.5 minutes, injection valves A3SV1 and A3SV2 are placed in the straight position so that the contents of sample loop A are injected into column 1. At the same time, injection valve A3SV3 is placed in the straight position to allow the sample to flow through sample loop B. The elution of any permanent gases are sensed by detector 1 between the 7.5- and 14.375-minute period. Column 2 inlet and outlet valves A4SV2 and A5SV2 are opened at 10.8 minutes to provide preliminary purging of column 2 before its use.

At 14.375, column 1 inlet and outlet valves are closed and injection valves A3SV1 and A3SV2 are placed in the cross position. The contents of sample loop B are then swept into column 2, while the sample is free to purge sample loop A. Column 3 inlet and outlet valves are opened at 45 minutes to provide 4.375 minutes purge time prior to use.

At 49.375 minutes, column 2 inlet and outlet valves are closed, and injection valves A3SV1 and A3SV2 are placed in the straight position. The contents of sample loop A are then swept into column 3, while the sample is free to purge sample loop B. At the sample time, sample selector

All valves used in this instrument are machined with great precision to very close tolerances. As might be expected with high precision parts, some difficulties were experienced with earlier versions of these valves. Difficulties were experienced with improper polarization of the solenoid magnets, thus leading to imcomplete valve closures. All O-rings used in these valves had to be selected for uniformity. Some of the original clearance dimensions for the O-rings were modified so that leakage past them could not occur even where there was sufficient slippage for the spindles to operate properly. Perhaps the greatest difficulty experienced with earlier valves was their tendency to have a slight leak between sample loops. This was remedied by careful adjustment of the spindle movement, and by "running-in" of the valves at $150^{\circ}F$.

3.3.2 Filters

Filters were used in the sample inlets of this system to prevent valve damage due to particulate matter in the samples. (See figure 5.) These filters also serve to prevent the entrance of liquid water droplets into the system. After investigation of several filter materials, glass fiber material with a pore diameter of 5 microns was chosen for this application. This material offered a resistance to flow of approximately 0.1 inch of water per ml/min flow. The filters were placed in a housing sealed by O-rings.

3.3.3 Check Valves

A check valve has been used at the head of the columns and at the head of the injection valve as illustrated in figure 5. The valve at the head of the columns is used to prevent the high pressure (42 psig) helium in the column assembly from backing up into the low-pressure sample (5 psia) at the time of injection. Prevention of this phenomenon allows the sample to be compressed near the column side of the sample loops, thus providing sharper injections. The check valve at the head of the injection valves was used to prevent the 1.0 ml of 42 psig helium released during injection from traveling towards the sample source. If this were to happen, good quantitative results could not be obtained on the following injection because the sample would be diluted with helium. Viton A duckbill valves housed in a special fitting were used for this application. These valves were found to close very rapidly and offered an impedance to flow of only 1 inch of water per ml/min sample flow.

3.3.4 Metering Device Assemblies

Tapered needle valves were incorporated into valve 1SV1 to control the flow of bypass sample and into valves A5SV1, A5SV2, and A5SV3 to control the detector pressure. The detectors were operated at 14.7 psia by adjusting the needle valves to provide a 14.7 psi pressure drop between the detectors and space vacuum. This pressure was chosen to provide optimum detector and column operation and to provide a long lifetime for the tritium foil within the detectors.

All other metering device assemblies consisted of a clamping assembly that compressed the stainless steel lead-in tubing until the proper restriction was obtained. Both types of metering devices, shown in figure 5, provided excellent flow control that remained constant after long periods of use.

4. ELECTRONICS

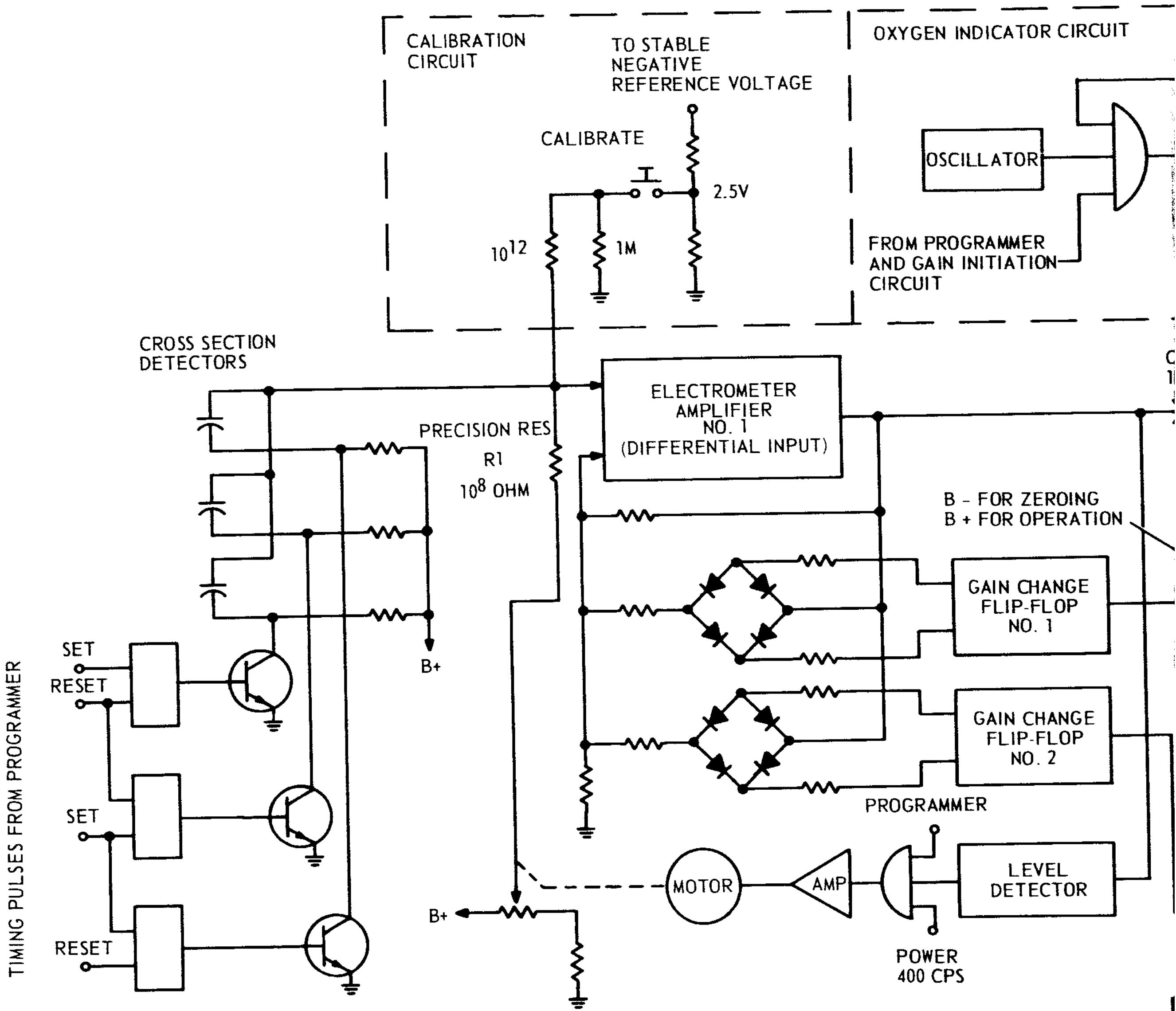
Initial efforts of the program were spent in developing a complete breadboard system to determine the optimum design criteria for the prototype system. Information such as amplifier gain needed, consistent with reasonable signal-to-noise ratios and detector sensitivity, and programming events were derived as a result of the integrated breadboard system. The breadboard system functional diagram is shown in figure 7.

4.1 Amplifiers

Although the breadboard system employed two Philbrick P-2 amplifiers, it was apparent that these amplifiers could not qualify for flight-type systems. Therefore, considerable effort was devoted to developing a high-impedance, all-silicon transistorized amplifier.

Coupled with the amplifier problem was the problem of suitably switching detectors. Several schemes were tried in attempting to solve both problems. The effort to develop a P-2 amplifier using silicon transistors was eventually cancelled. The difficulties in achieving an amplifier sufficiently small and possessing good stability would require more experimental time than this program would permit. Some of the input schemes tried were: (a) bootstrapped field effect transistor amplifiers of unity gain (figure 8) employing positive and negative feedback to develop high input impedance of a standard low-input impedance operational amplifier (figure 9); (b) a chopper stabilized amplifier (figure 10); and (c) a parametric amplifier employing a variation diode (figure 11). All of these schemes exhibited excessive noise properties in the band of interest which extends from a small fraction of a cycle to one cycle per second. In the

R8465



CALIBRATION CIRCUIT
TO STABLE NEGATIVE REFERENCE VOLTAGE
CALIBRATE
2.5V
10^{12}
1M
OXYGEN INDICATOR CIRCUIT
OSCILLATOR
FROM PROGRAMMER AND GAIN INITIATION CIRCUIT
CROSS SECTION DETECTORS
ELECTROMETER AMPLIFIER NO. 1 (DIFFERENTIAL INPUT)
PRECISION RES R1 10^8 OHM
B - FOR ZEROING
B + FOR OPERATION
GAIN CHANGE FLIP-FLOP NO. 1
GAIN CHANGE FLIP-FLOP NO. 2
PROGRAMMER
B+
SET
RESET
SET
RESET
TIMING PULSES FROM PROGRAMMER
MOTOR
AMP
LEVEL DETECTOR
POWER 400 CPS
B+

28

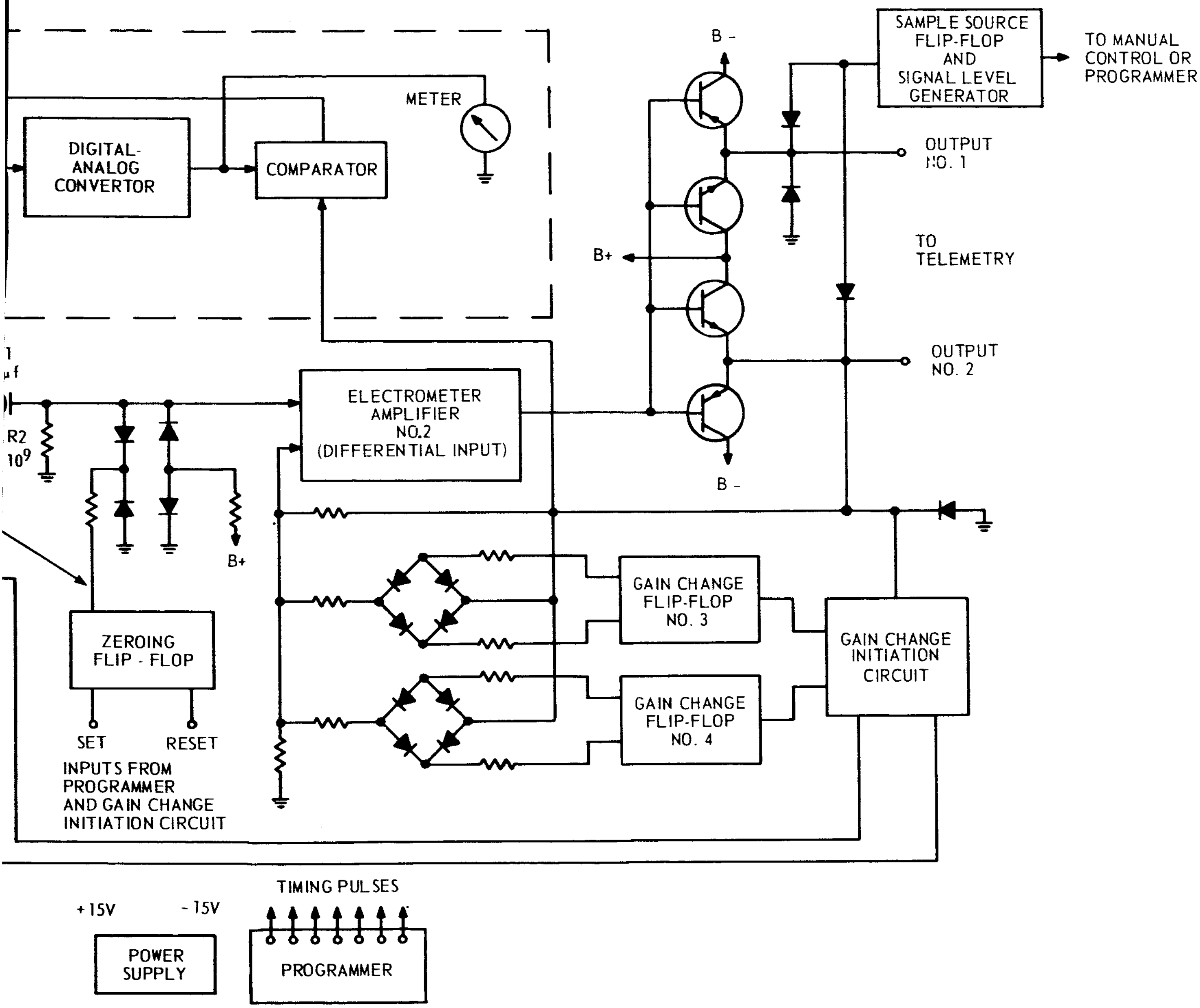
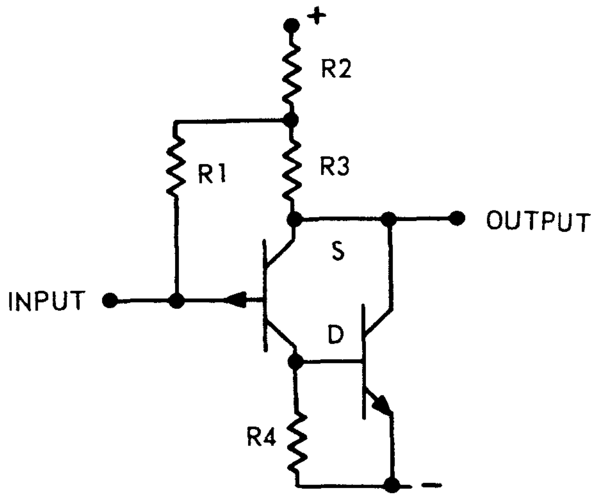


Figure 7. Function Diagram of Breadboard Electronic System

2



$$R_{IN} = G_{AN}\left(\frac{R_2}{R_2+R_3}\right) \quad R_1$$

Figure 8. Schematic Diagram of a DC Coupled Bootstrapped Source Follower

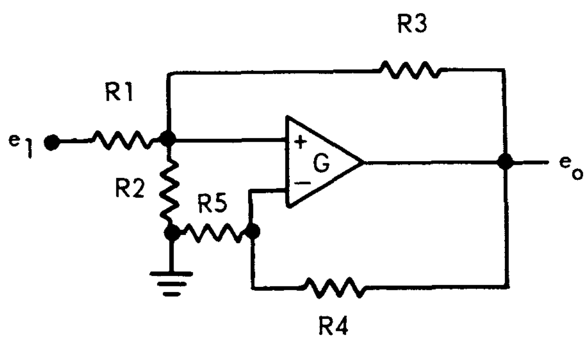


Figure 9. Simplified Representation of Buffer-type Amplifier Circuitry

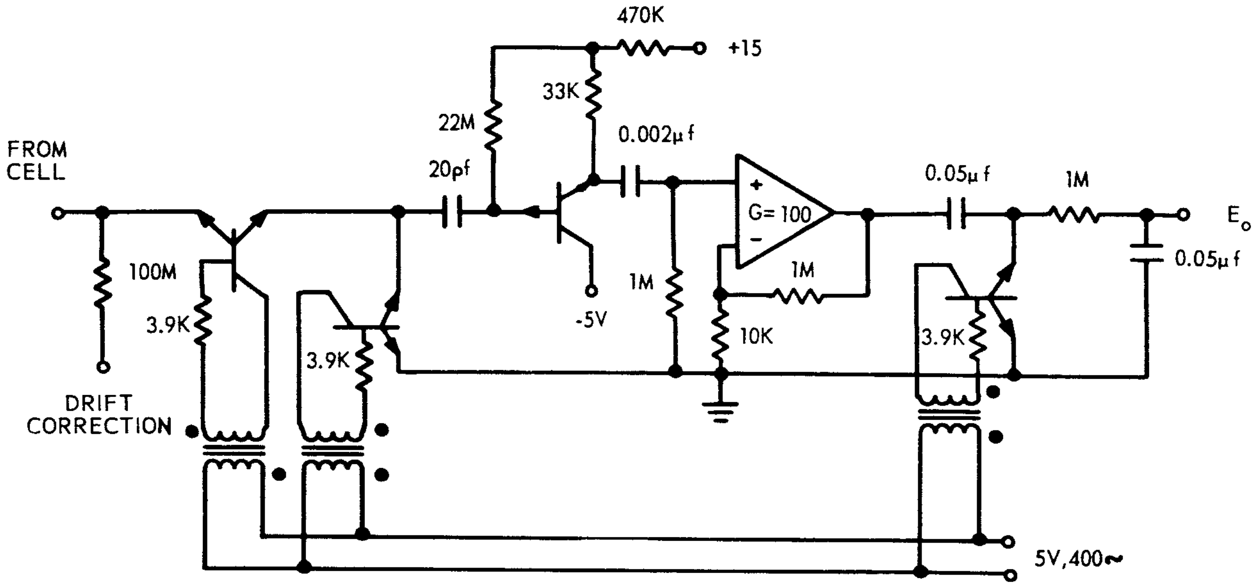


Figure 10. Chopped Stabilized Amplifier

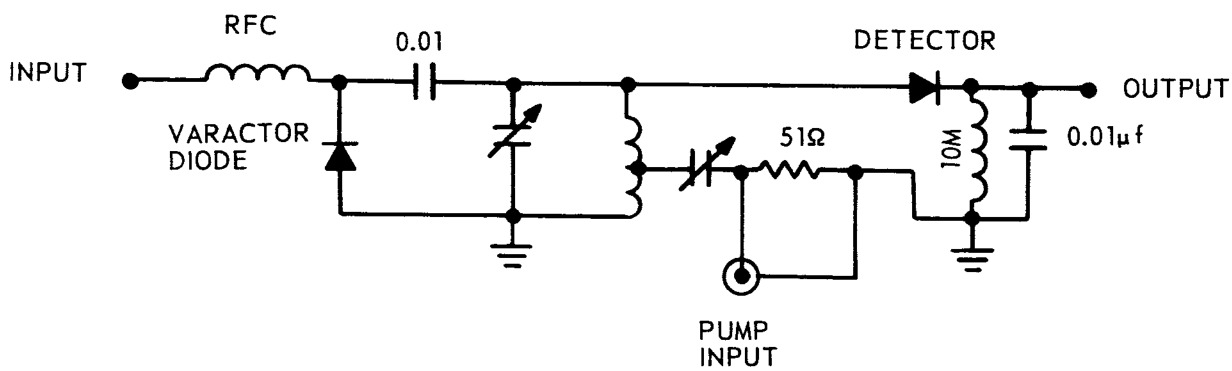


Figure 11. Varactor Amplifier

final analysis, Philbrick researchers developed an all-silicon transistor amplifier having specification exceeding those of the P-2 amplifier employed in the breadboard unit. The amplifier was modified to reduce its size and weight and was employed in all subsequent systems. Detector switching was best solved by employing two latching-type relays.

4.2 Zeroing System

The development of a zeroing circuit to cancel the static background current of the detector was completed for the breadboard system. The initial system employed an electromechanical zeroing servo which was unsatisfactory from a reliability point of view. A system shown in figure 12 was designed to perform the zeroing function. The circuit performed its intended function well but had an undesirable effect on the RC time constant. The zeroing system finally used was a 5-stage counter and a digital-to-analog converter. This system is included in figure 13 and is described in section 4.4.

4.3 Automatic Gain Change

Automatic gain changing was developed during the breadboard phase of the program. The initial design employed diode quads to accomplish the gating and effectively switch in different feedback resistors to change the amplifier gain. (Refer to figure 7.) The diodes in these quads required matching to within 1 millivolt to achieve stable operation in the amplifiers. The manufacturer of these diodes would only guarantee this match over a temperature range of 0.2° to 150°F. The double emitter transistor, especially designed and specified for chopper switch operation is ideally suited for this application. Offset voltages considerable less than 1 millivolt are obtainable even in an uncontrolled temperature environment. A great deal of circuitry was eliminated as a result of using the double emitter transistor.

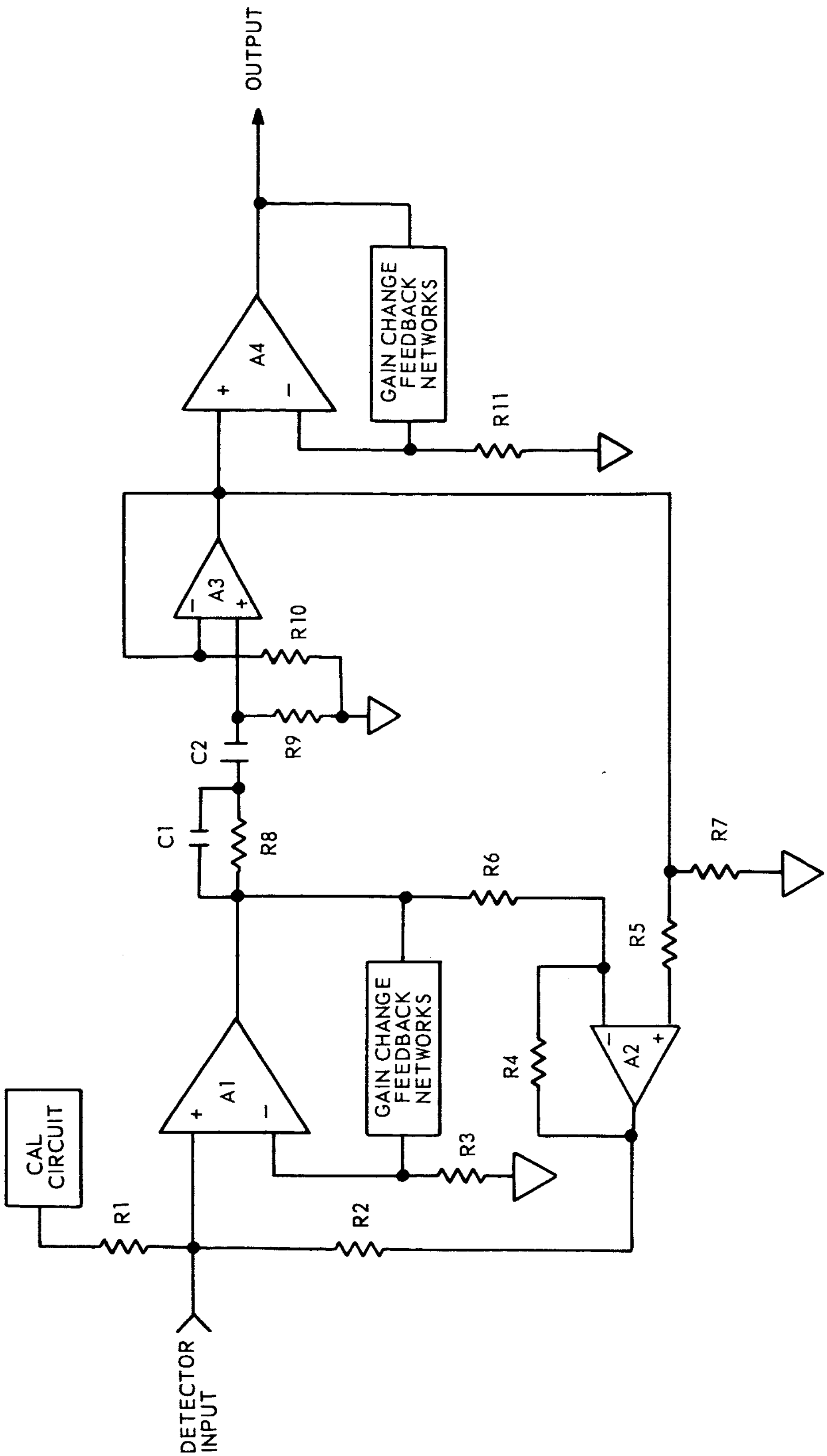
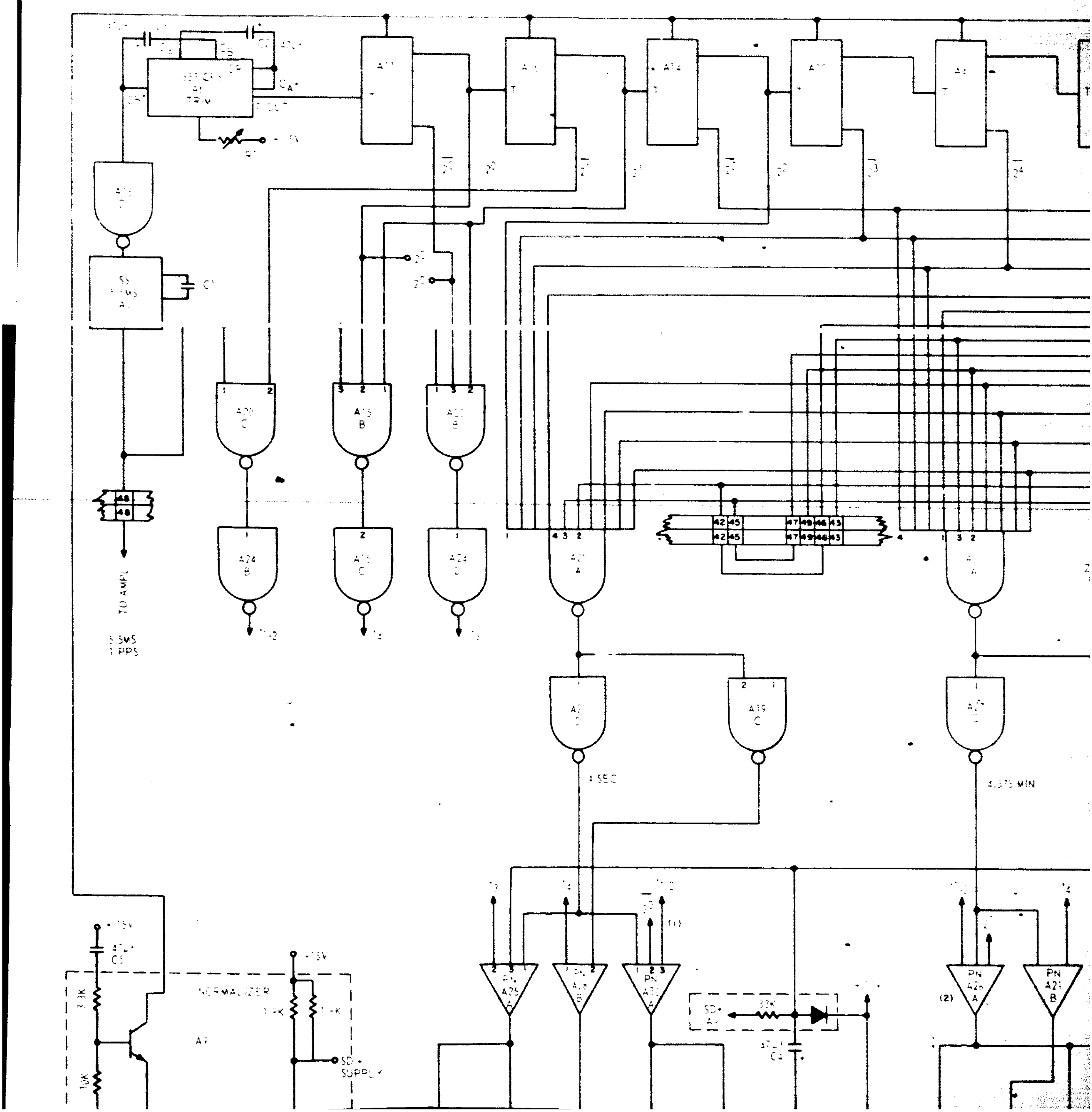
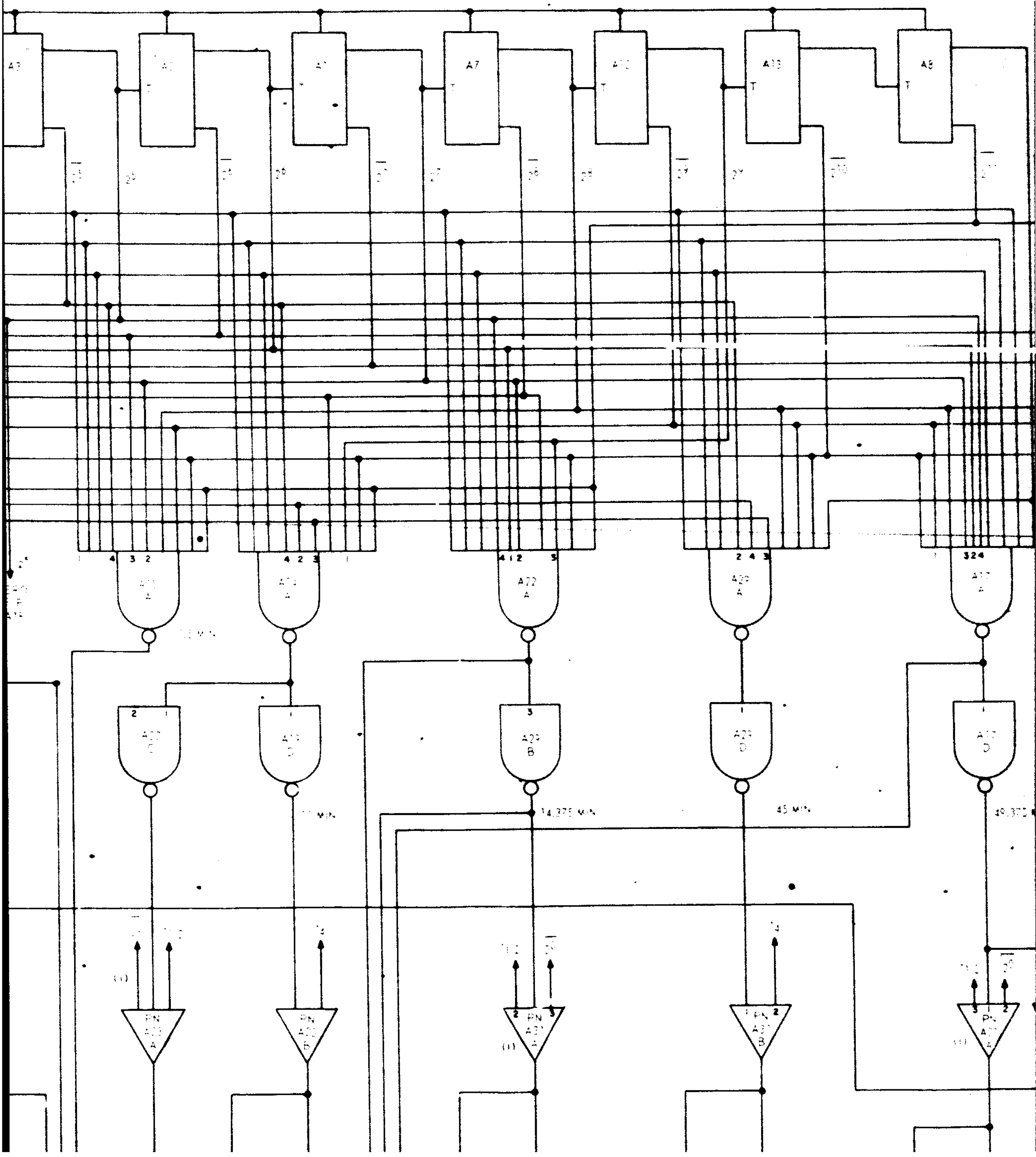


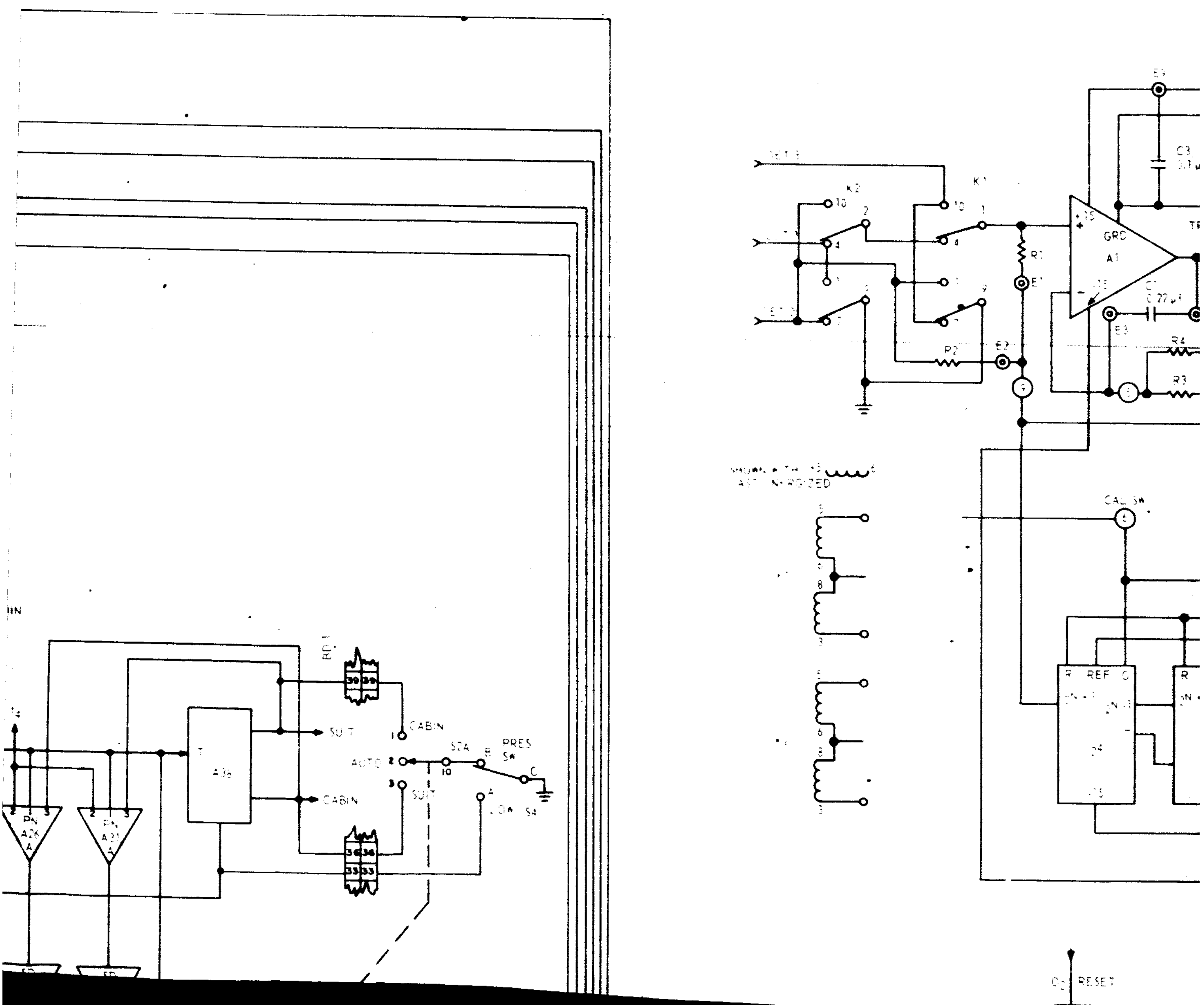
Figure 12. Baseline Zeroing Circuit


A14
A13
SS
A1
C1
A20
C
A15
B
A22
B
A24
B
A24
C
A15
C
A21
A
A21
D
A19
C
TO AMPL
5.5MS
NORMALIZER
A7
SD+
SUPPLY
R1
C2
C4
C5
4 SEC
PN
A25
A
PN
A28
B
PN
A30
A
PN
A26
A
PN
A21
B
3.3K
10K
33K
47µF

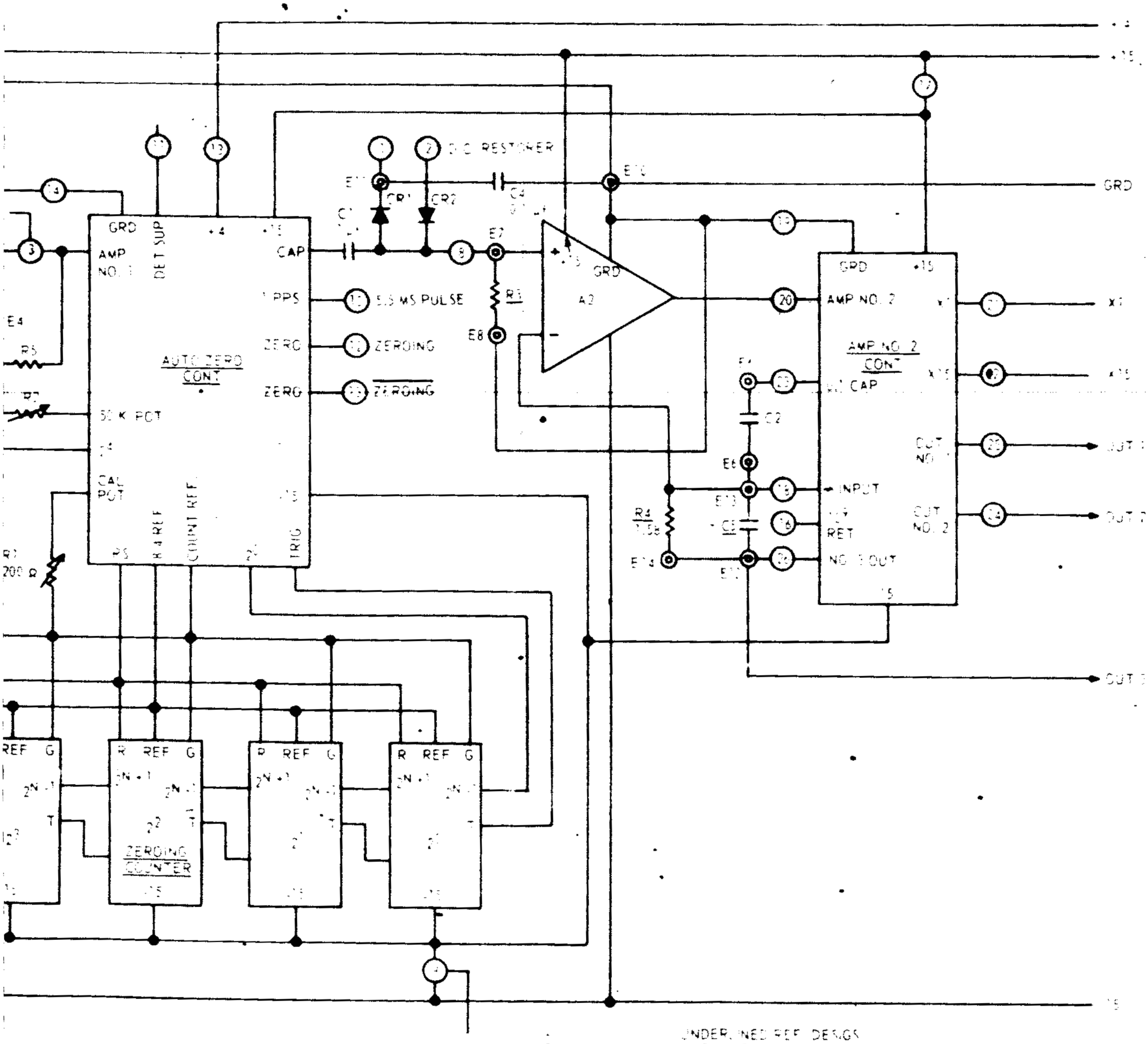
34:2



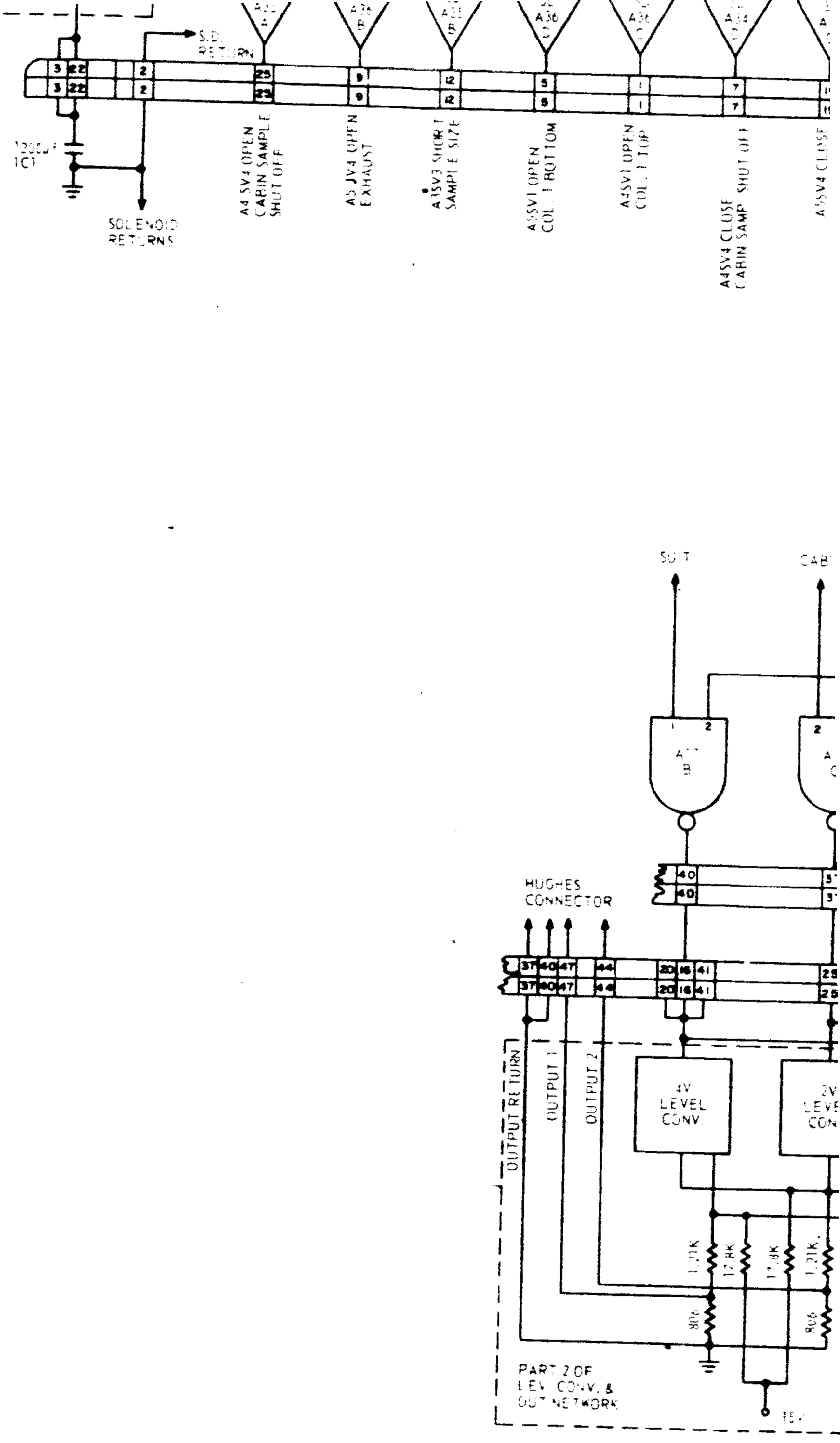
34.3

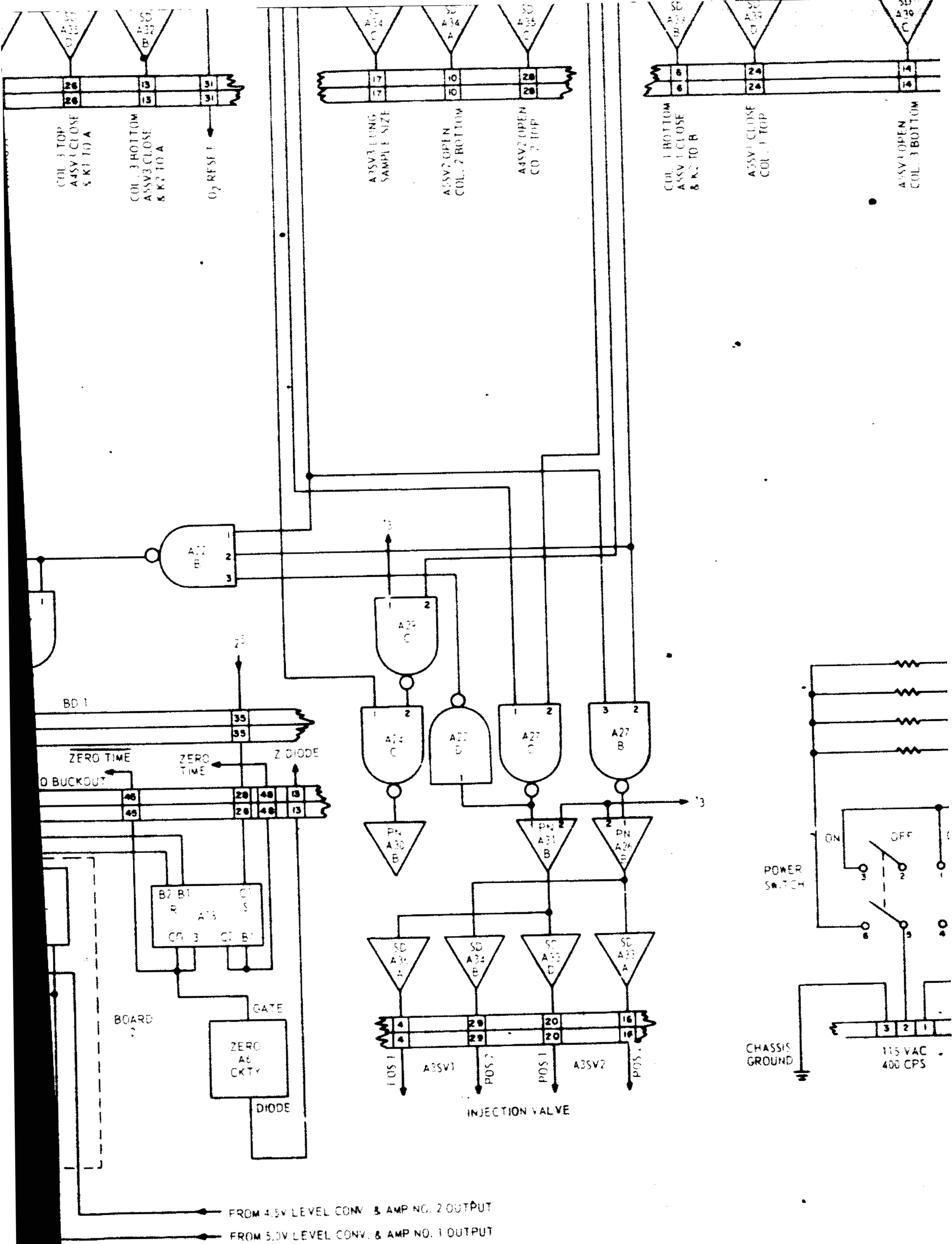


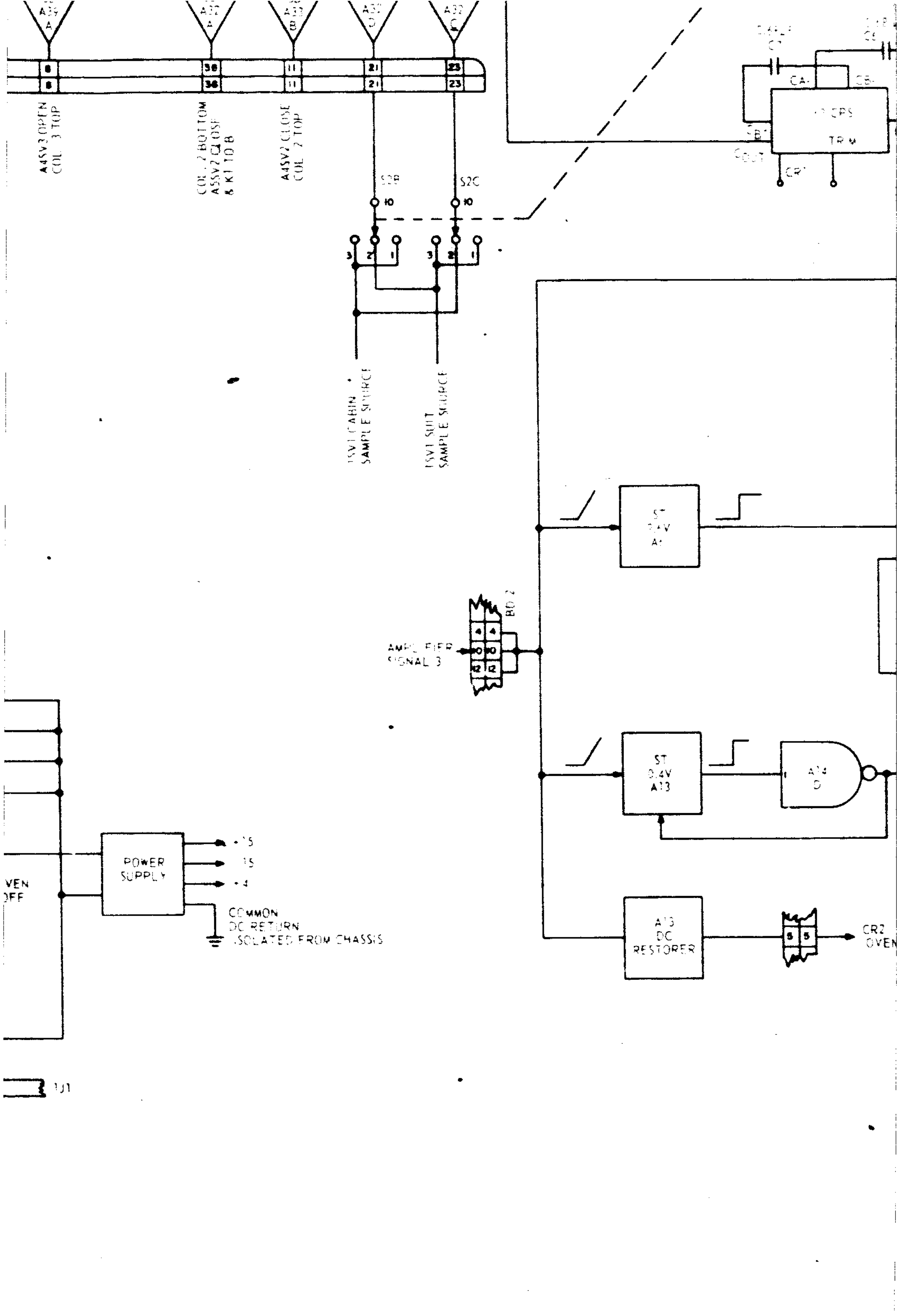
K2
K1
C3
GRD
A1
R1
E1
R2
E2
E3
R4
R3
CAL SW
REF
RESET
A36
PN
A26
A31
SUIT
CABIN
AUTO
S2A
PRES
SW
LOW
S4

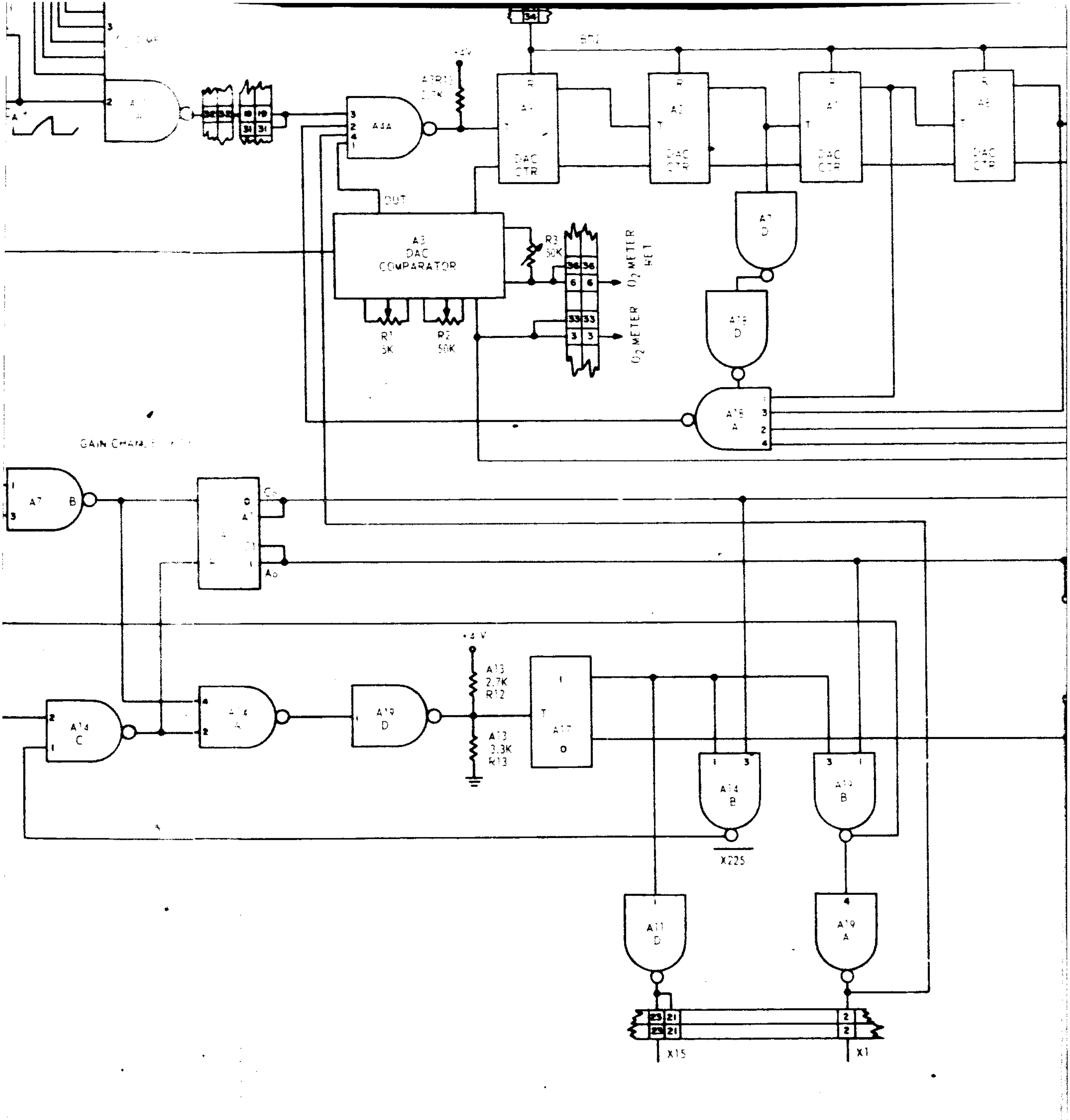


UNDERLINED REF DESIGS
ARE OVER ASSEM. COMPONENTS
OTHERS ARE AT COMPONENTS


S.D. RETURN
1200µF
1C1
SOLENOID RETURNS
A4 SV4 OPEN CABIN SAMPLE SHUT OFF
A5 SV4 OPEN EXHAUST
A3SV3 SHORT SAMPLE SIZE
A3SV1 OPEN COL. 1 BOTTOM
A4SV1 OPEN COL. 1 TOP
A4SV4 CLOSE CABIN SAMP SHUT OFF
SUIT
HUGHES CONNECTOR
OUTPUT RETURN
OUTPUT 1
OUTPUT 2
4V LEVEL CONV.
PART 2 OF LEV. CONV. & OUT NETWORK


O2 RESET
A3SV3 LUNG SAMPLE SIZE
A5SV1 CLOSE COL. 1 TOP
BD 1
ZERO TIME
ZERO TIME
Z DIODE
O BUCKOUT
BOARD 2
GATE
ZERO A6 CKTY
DIODE
A3SV1
A3SV2
INJECTION VALVE
POWER SWITCH
ON
OFF
CHASSIS GROUND
115 VAC 400 CPS
FROM 4.5V LEVEL CONV. & AMP NO. 2 OUTPUT
FROM 5.0V LEVEL CONV. & AMP NO. 1 OUTPUT


A4SV3 OPEN
COL 3 TOP
COL 2 BOTTOM
A5SV2 CLOSE
& K1 TO B
A4SV2 CLOSE
COL 2 TOP
S2B
S2C
SAMPLE SOURCE
TSV1 SUIT
SAMPLE SOURCE
C7
CA
CB
TRIM
CR1
BD 2
AMPLIFIER
SIGNAL 3
ST
A13
A14
D
A13
DC
RESTORER
CR2
POWER
SUPPLY
COMMON
DC RETURN
ISOLATED FROM CHASSIS



34
BP2
+4V
A3R15
A4A
OUT
DAC CTR
A3
DAC
COMPARATOR
R3
50K
R1
5K
R2
50K
O2 METER
RET
O2 METER
36
6
33
3
GAIN CHANGE
A7
B
A14
C
A19
D
+4 V
A13
2.7K
R12
A13
3.3K
R13
A17
X225
A11
D
A19
A
X15
X1

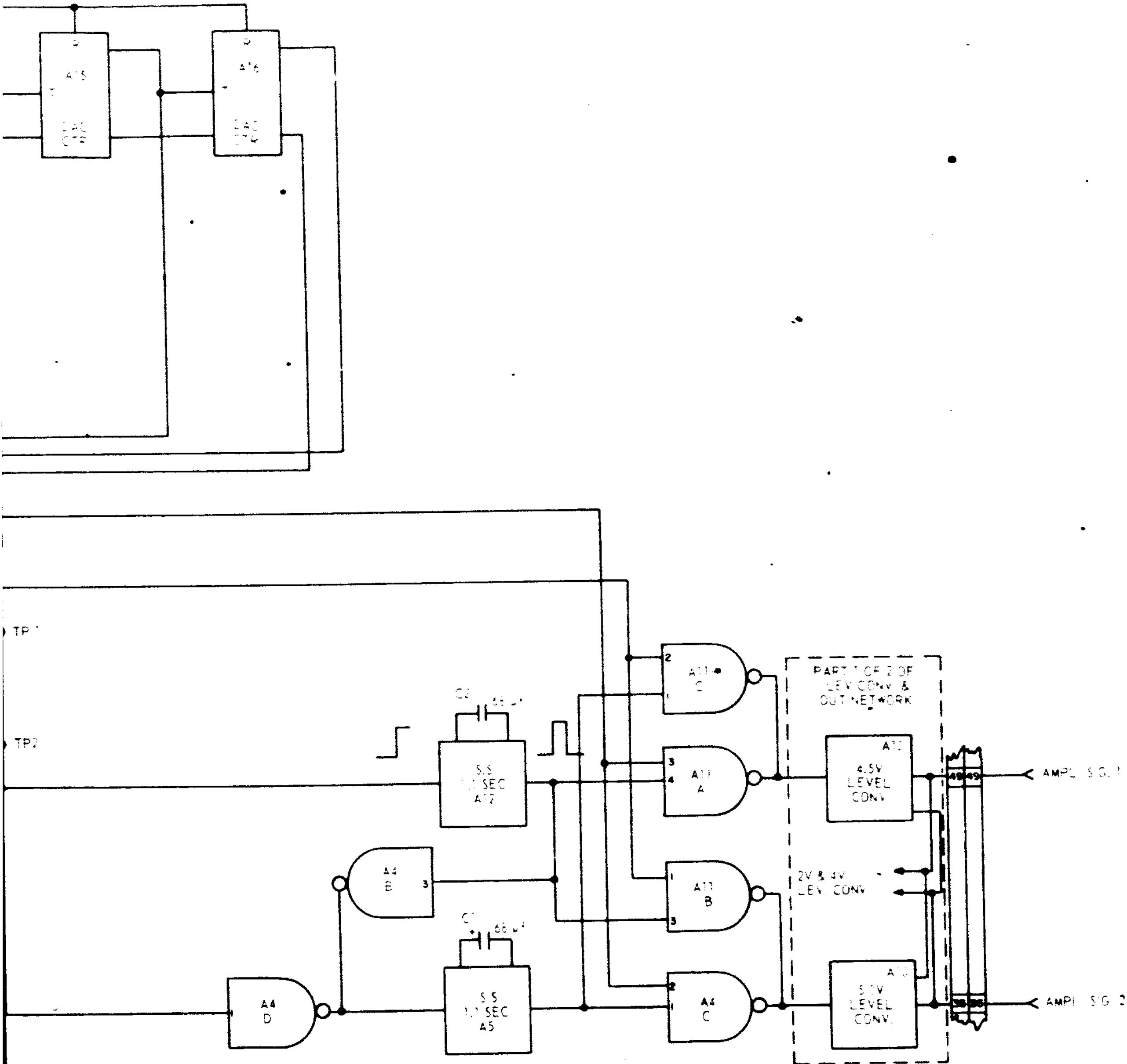


Figure 13. System Logic Diagram

4.4 System Logic

A logic diagram showing the overall function of all the electronic circuits in finalized form is shown in figure 13. All of the electronics are packaged on three mother boards. The circuits were divided and allocated to some 12 different types of modules. The modules were constructed in cordwood fashion and welded. The total number of cordwood modules used was 65. The Timer and Valve Control Assembly (R449266) used 39 modules. The O_2 and Amplifier Control Assembly (R449267) used 19 modules and the Amplifier Control Assembly (R449301) used 7 modules. The distribution and function of those modules is shown in table 3.

In the following discussion of the electronic theory of operation, refer to the Systems Logic Diagram (figure 13). When S1 the front panel power switch is placed in the start position, 400-cycle power is connected to the Heater Control Assembly and the System Power Supply allowing the system to function as the oven is heated to 150°F. The dc voltages are now available to the logic modules and as the normalizer capacitor, 1A1C5, charges, the normalizer circuit (part of 1A1A9) applies a reset, ground level to the counter chain 1A1A1 through A4, A7, A8, A10 to A14 and A16, resetting the counters in the chain to zero. A6 is a free running multivibrator with a basic clock period of 1.17 seconds. The multivibrator and counters run continuously as long as the power switch S1 is in the START position. A natural reset condition occurs every 80 minutes.

NAND decoding gates are operated from the counter outputs. The outputs from A11 and A16 are gated with 5.5 millisecond pulses from A5. A24B output is two pulses, one at t_1 and one at t_2. The t_3 and t_4 pulses

TABLE 3

DISTRIBUTION OF MODULES

Assembly R449266	Assembly R449267	Assembly R449301	Total	Function
13	1		14	Counter
	6		6	DAC counter
		5	5	Zeroing counter
8	5		13	4-3-2-1 NAND Gate
8			8	3-2 Power NAND
6			6	Solenoid driver
1	2		3	Single shot multi.
2	1		3	Free running multi.
1			1	Diode matrix
	1		1	DAC comparator
	1		1	9.6 U Schmitt Trigger
	1		1	0.4 U Schmitt Trigger
	1		1	Level converter & output net.
		1	1	Automatic zeroing control
		1	1	No. 2 amplifier control
39	19	7	65	

shown in figure 3 are outputs from A24D and A15C, respectively. The A sections of NAND modules A20, A27, A15, A24, A22, A29, and A17 decode from the counters, via a diode matrix A9, timing pulses of 4.5 seconds in duration. Each gate decodes one pulse per 80-minute cycle. These pulses are inverted and ANDed together with t_3, t_4 or t_{1-2} and 2^0 or $2^{\bar{0}}$ (outputs from A11 counter). This AND operation is provided by power NAND gates. These power NAND gates drive up to two solenoid driver circuits which operate the latching solenoid operated valves. See figure 5 for the time sequence of valve operation. Counter module A38 is not a part of the timing counter chain but is controlled by S2, the sample source selector, and S4, the absolute pressure switch. This counter stores the sample source information.

If the absolute pressure in the spacecraft cabin is greater than 3 psia and S2 is in the Cabin position, A38 is held in the cabin position and SV1 cannot be actuated to allow suit air to the sample loops. Should S2 be placed to suit or low cabin pressure (less than 1.5 psia) and cause S4 to actuate, A38 counter would be set to the suit condition; however, the power NANDs that operate SV1, the sample source valve, are not activated until 45 minutes from the first injection. The timing pulses that contain injection command are OR'd together by A22B in conjunction with A22D and A27C. The output of A22B allows either the suit or cabin signal to the Level Converter module via NANDs A17B and A17C, respectively.

The following discussion concerns those modules found on the O_2 and Amplifier Control Assembly, and all reference designations are preceded by 1A2 except when the reference designation is not abbreviated. The second actuation pulse (t_2) for the first injection time (t - 0) enables power NAND, 1A1A28A, which, among other things, applies a ground reset level to the O_2 D.A.C. Counters A1, A2, A8, A9, A15 and A16. Each of the counters drives one section of a ladder-type digital-to-analog converter which is included in the counter module. When reset, this D.A.C. output is zero. During the interval from 0.625 minute to 1.875 minutes past the first injection, 1A1A18A sections NAND allows clock pulses from 1A1A18, a free running multivibrator. A3, the D.A.C. Comparator, monitors the amplifier signal No. 3 (0-10 volt amplifier output) and the D.A.C. output, and when the amplifier output is greater than the D.A.C. output, an enable level (logical 1) is applied to A4A-1. During the time that the clock pulses are coming to A4A, the oxygen peak is being detected and amplifier signal No. 3 is tracing the peak. Since the peak is large, the X1 gain signal is a logical 1 on pin 4 of A4A. A4A-2 is a 1 and the clock pulses are applied to the first counter, A9. The counters will increase the D.A.C. output until it is larger than the amplifier signal; thus, the D.A.C. will follow the oxygen signal up to the peak but not down the falling side of the signal. The D.A.C. Comparator drives the O_2 meter in proportion to the D.A.C. output. If the oxygen signal were large enough to increase the counter to a full count, NAND A18A inhibits the clock and a full-scale indication is given on the O_2 meter.

The gain-changing circuitry is actuated by the amplifier signal No. 3, with the gain information being stored by flip-flop A7 and counter A17. Gain is controlled by switching in feedback resistors across High Impedance Amplifier No. 2. A typical output response with gain changes is shown in figure 14. Assume this amplifier gain to be highest at 225. As the amplifier signal No. 3 rises to 9.6 volts, A6, a Schmitt Trigger, puts out a

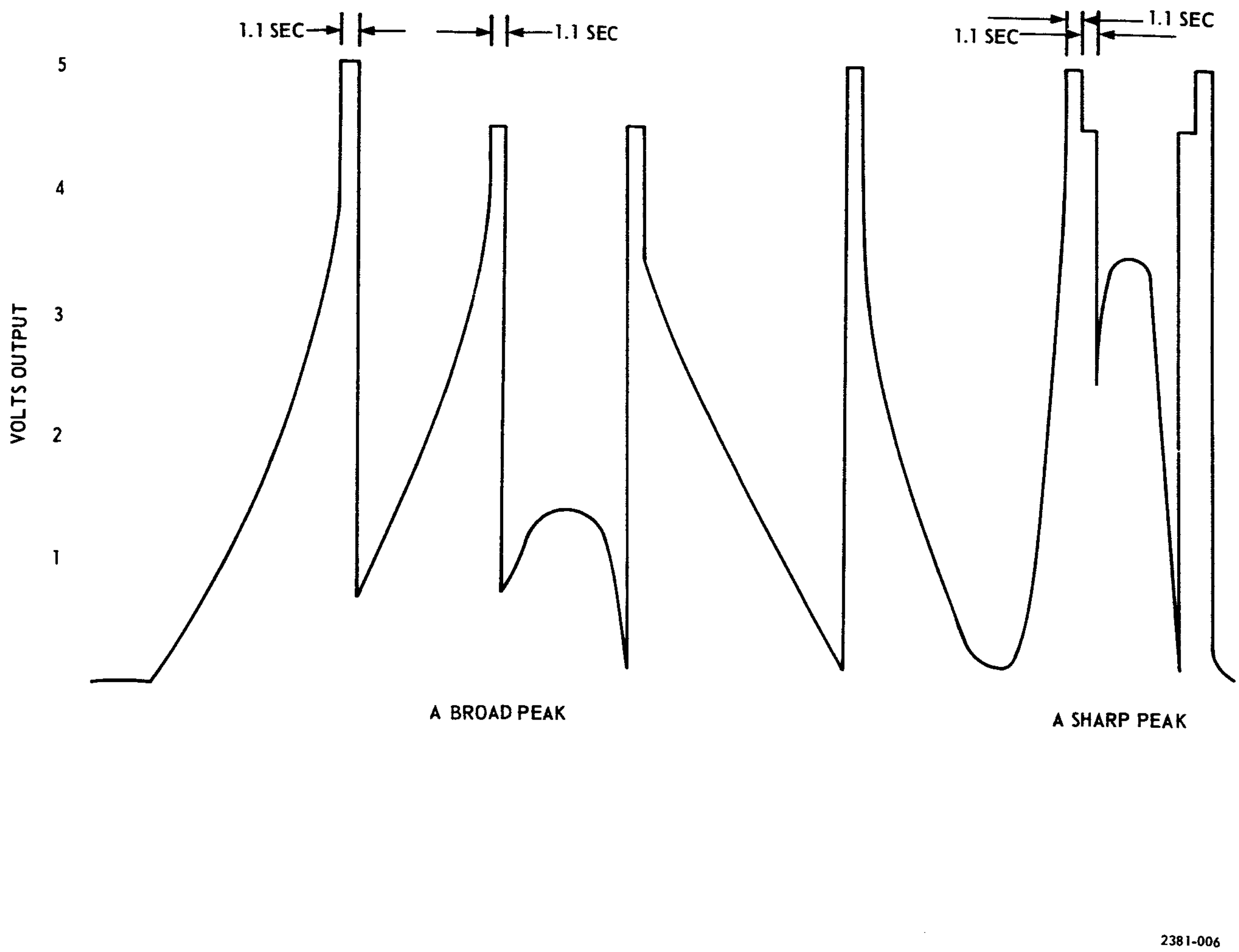
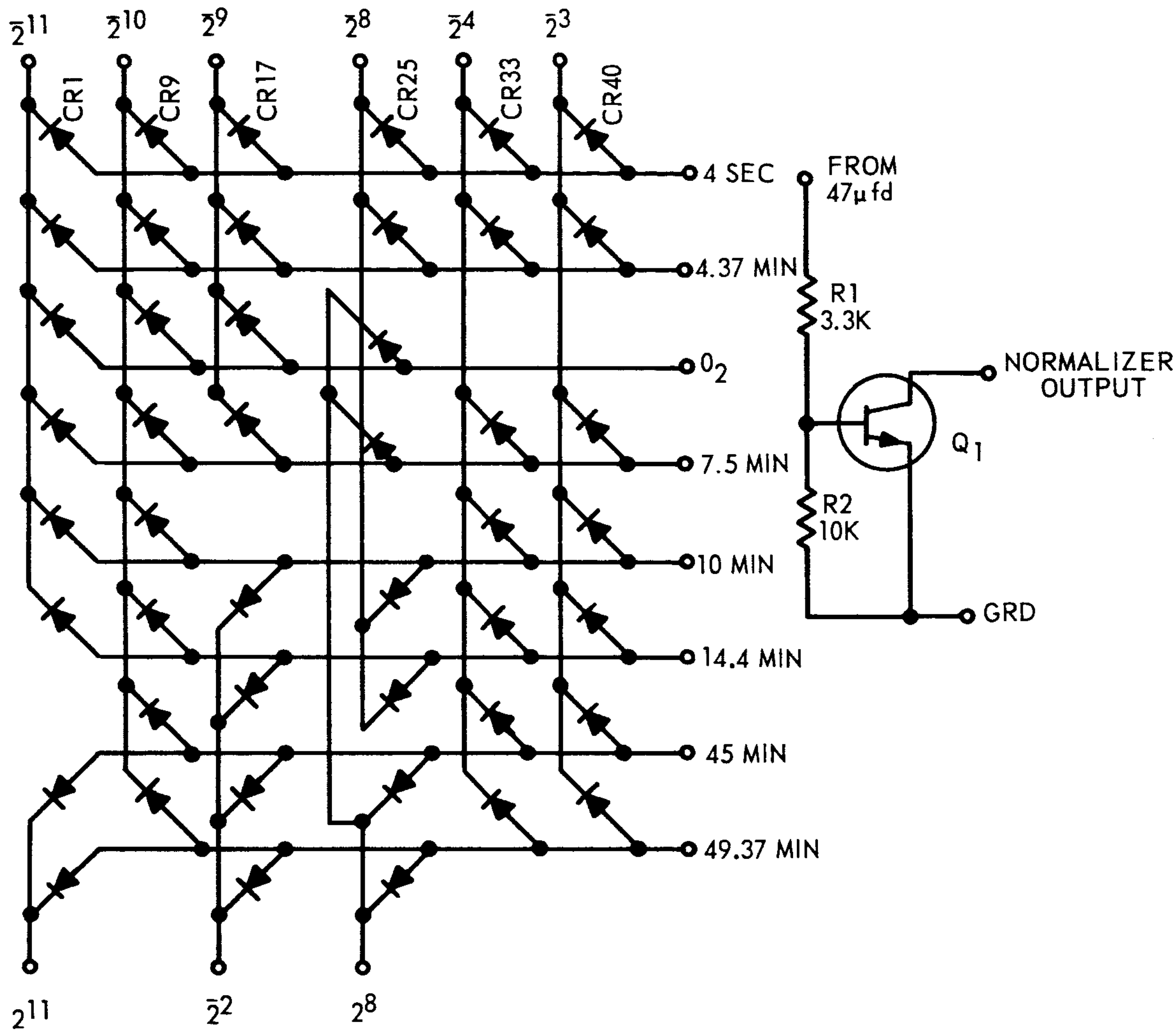


Figure 14. Peaks with Gain Changing

logical 1 which sets A7 and triggers A17. This state of A17 signifies an X15 gain signal. The transistion of A17 also actuates A12, a single-shot multivibrator, whose output pulse is gated to the 5-volt Level Comparator A10. When the X15 gain signal is applied to the No. 2 Amplifier Control module in the oven, the amplifier signal No. 3 drops quickly to approximately 0.6 volts. If this signal continues to rise, A6 will trigger again at 9.6 volts. This time only A17 will change state; this condition of A7 and A17 is decoded to be an X1 gain signal. Single-Shot A5 is actuated on this transition of A17, but its output goes to the 4.5-volt Level Converter.

X1 is the minimum gain configuration. Now, should the amplifier signal No. 3 drop to 0.4 volt, Schmitt Trigger A13 will fire, resetting A7 and triggering A17. A17 is again in the X15 condition and A12 is again actuated; however, the output of A12 is this time gated to the 4.5-volt Level Converter. When the amplifier signal level again drops to 0.4 volt, A17 is again triggered and the X225 state of A17 and A7 is decoded. A5 is triggered and its output is gated to the 5.0-volt Level Converter section. The 2- and 4-volt Level Converter inputs are supplied by the cabin and suit signals from 1A1A17C and 1A1A17B, respectively. Either of these inputs will reset the zeroing flip-flop A18, which drives the Zeroing Circuitry in A6. This causes the amplifier signals to go to ground while a different detector is being connected to the amplifier. The 2^5 level from 1A1A3 sets A18 back to its nonzeroing state, thus allowing 37.5 seconds of zeroing time.

Logic Modules: The Diode Matrix and Normalizer, R353281-1, contains three separate circuits, a diode matrix, a normalizer circuit and a solenoid driver actuating circuit. The schematic diagram is shown in figure 15. The



QTY	PART NO.	CKT SYM
46	479-0468-001	CR1 - CR46
1	472-0153-001	Q1
1	R352869-75	R1
1	R352869-87	R2

ASSEMBLY NUMBER
R353281

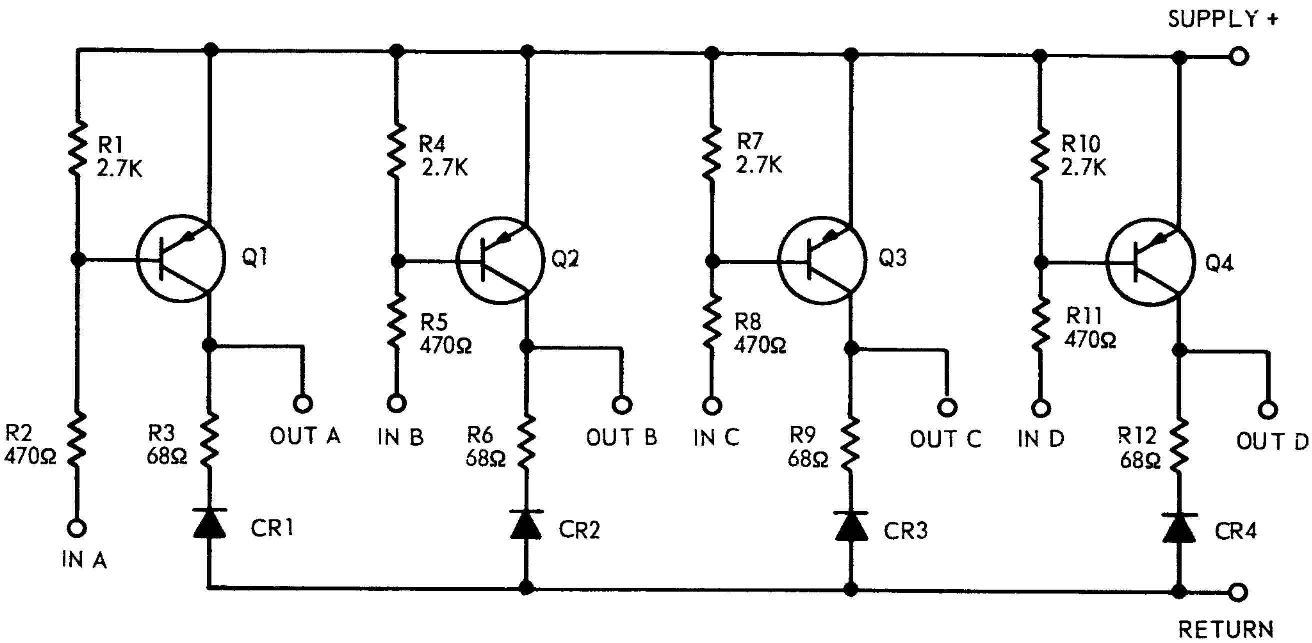
DIODE MATRIX AND NORMALIZER

2381-007

Figure 15. Diode Matrix and Normalizer (R353281-1)

diode matrix is composed of seven groups of diodes; each group has its anodes connected together in a common output. The group is connected externally to the node of an A section NAND thus making the NAND one of 10 inputs. The normalizer is driven from the positive 15-volt supply through a 47-microfarad capacitor. As the power supply is turned on, the capacitor 1A1C5 begins to charge up turning transistor Q1 on. This produces the required ground level at Q1 collector. The remaining circuit has two 1.8 K resistors in parallel between the +15-volt supply and the solenoid driver supply capacitor; this is a 900-ohm charging path for the capacitor. From the solenoid driver supply there is a 33 K resistor to a point connected to S4-A, the normally open terminal of the pressure switch. This point is connected to external 22 microfarad capacitor C4 that drives the solenoid driver for the cabin shutoff valve. Low cabin pressure could actuate S4 causing S4-A to go to ground. C4, which was initially uncharged with 15 volts on both sides, now begins to charge to +15 volts from the solenoid driver input. This charging actuates the solenoid driver closing the cabin shutoff valve. If the cabin pressure remained high and the +15 volts was removed by shut-down or power failure, the diode, CR47 of this module, would ground the negative side of C4 also and the cabin shutoff would close again.

Solenoid Driver module, R353283-1, contains four identical sections as shown in figure 16. Each section is a simple PNP driver circuit whose collector circuit provides a discharge path for the coil when it is de-energizing, thus preventing any high voltage spikes from the coil. The Free Running Multivibrator, figure 17, R353284-1, is of standard configuration with a



QTY	PART NO.	REF DESIG
4	479-0002-001	CR 1 TO CR 4
4	472-0014-001	Q1 TO Q4
4	R352869-73	R1, 4, 7, 10
4	R352869-55	R2, 5, 8, 11
4	R352869-35	R3, 6, 9, 12

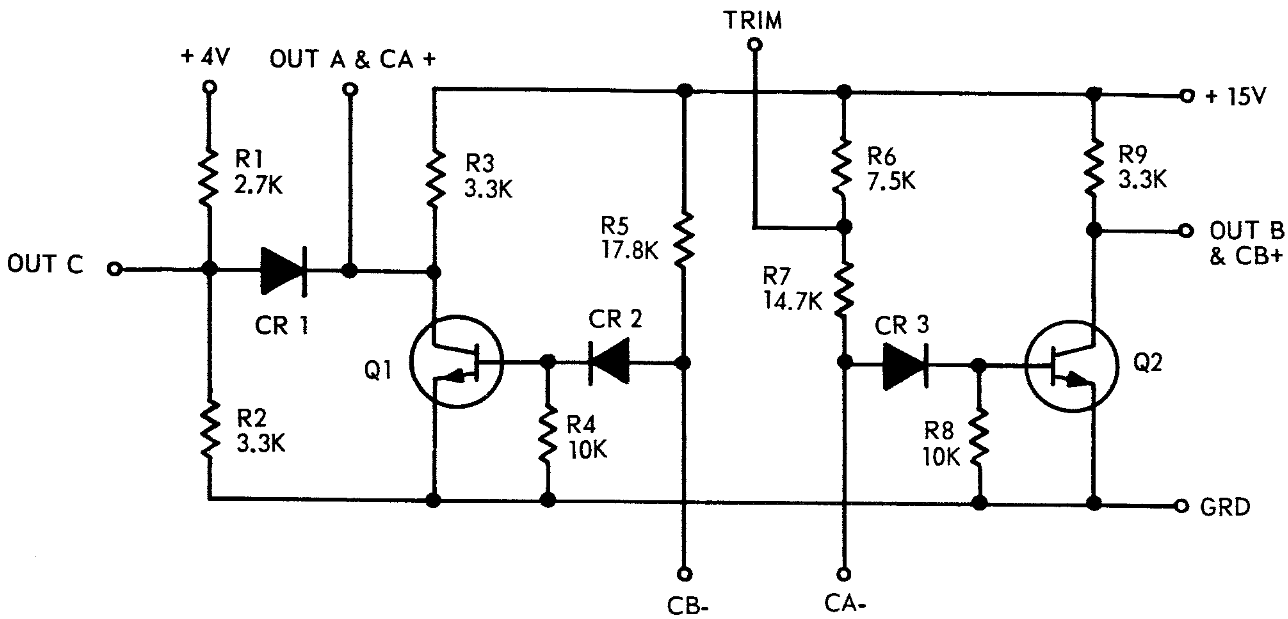
AVG DISSIPATION = 0
MAX 38.5 MW X dv/CKT

SOLENOID DRIVER X4
(RELAY)

ASSEMBLY NUMBER
R353283

2381-009

Figure 16. Solenoid Driver (R353283-1)



QTY	PART NO	REF. DESIG.
3	479-0468-001	CR1, 2, 3
2	472-0153-001	Q1, 2
1	R352869-73	R1
3	R352869-75	R2, 3, 9
2	R352869-87	R4, 8
1	R448219-325	R5
1	R448219-285	R6
1	R448219-317	R7

ASSEMBLY NUMBER
R353284

POWER IN = 95MW

	IMAX	I MIN
+4V	1.3MA	0.67MA
+15V	6.25 MA	5.31MA

PERIOD T = 0.025C (IN SEC)
WHERE $C = C_A = C_B$ (IN μF)
$T = 0.012C_A + 0.013C_B$
WHERE $C_A \neq C_B$

TRIM = ± 6% WITH 0-10K POT
TO + 15V

MULTIVIBRATOR,
FREE RUNNING

2381-010

Figure 17. Free-Running Multivibrator (R353284-1)

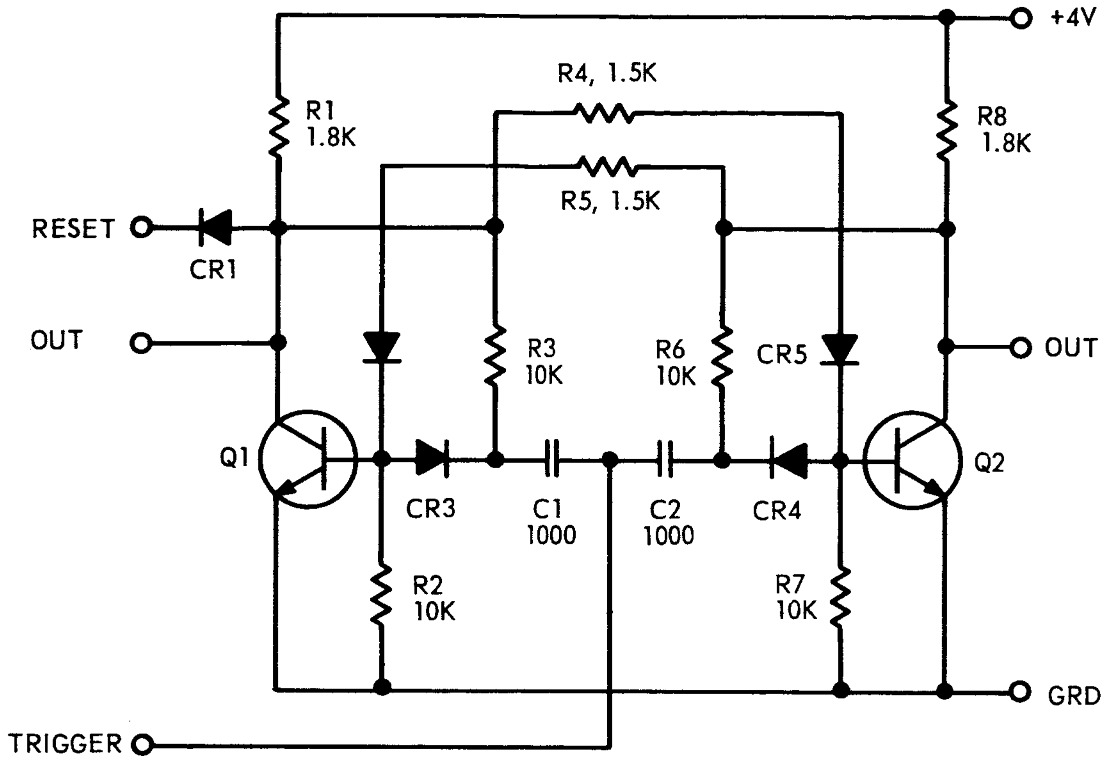
separate clamping circuit included. The clamping circuit of module 1A1A18 is used as a pull-up for NAND 1A1A17D, which is necessary when driving a counter trigger input. The Counter Module, figure 18, R353285-1, is a basic binary flip-flop with an ac trigger and one reset input.

NAND Module, figure 19, R353286-1, has four sections, each with a different number of input diodes, one, two, three or four. The four-input section has an external connection to the circuit node allowing connection of more input diodes via the diode matrix. The output will go to a ground level if, and only if, all inputs in that section are at a logical 1 (greater than +1.5 v) or open. A ground level on any input will allow the output to go to a logical 1.

The power NAND Module, figure 20 (R353282-1), contains two separate circuits; one has three inputs and the other has two. Both circuits are basic NAND's followed by a power transistor.

The 9.6-v Schmitt Trigger, shown in figure 21, is actuated by its input going above 9.6 volts with the output going from zero to one at this time. Since Q1 and Q2 have unequal collector resistors, the current through R5 changes as the circuit is triggered and the input reference level changes producing a hysteresis effect; i.e., the output will return to ground when the input drops below approximately 6 volts. The zeroing control circuit is a resistive level shifter which causes the zeroing diode output to go from +10 to -2 volts as the Zeroing Gate input goes to ground.

The 0.4-volt Schmitt Trigger and DC Restorer, figure 22, R353289-1, contain two separate and different circuits. The Schmitt Trigger actuates at an input signal level of 0.46 volt allowing the output to go positive.



QTY	PART NO.	REF. DESIG
5	479-0468-001	CR1 TO CR5
2	R448218-66	C1, C2
2	472-0153-001	Q1, Q2
2	R352869-69	R1, R8
4	R352869-87	R2, R3, R6, R7
2	R352869-67	R4, R5

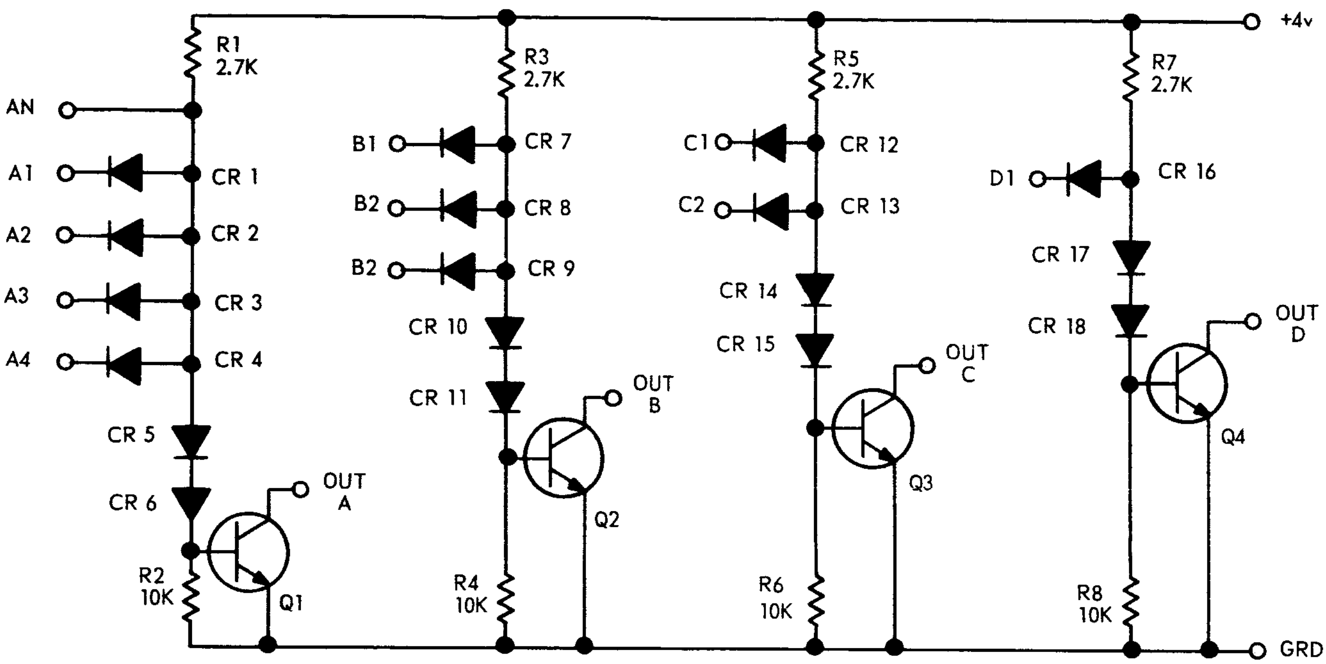
ASSEMBLY NUMBER
R353285

DISSIPATION = 12 MW
+ 4V CURRENT = 3.1 MA

FANOUT = 5
COUNTER

2381-011

Figure 18. Counter Module (R353285-1)



QTY	PART NO.	REF DESIG.
18	479-0468-001	CR1 TO CR18
4	472-0153-001	Q1 TO Q4
4	R352869-73	R1, 3, 5, 7
4	R352869-87	R2, 4, 6, 8

DISSIPATION = 20 MW MAX

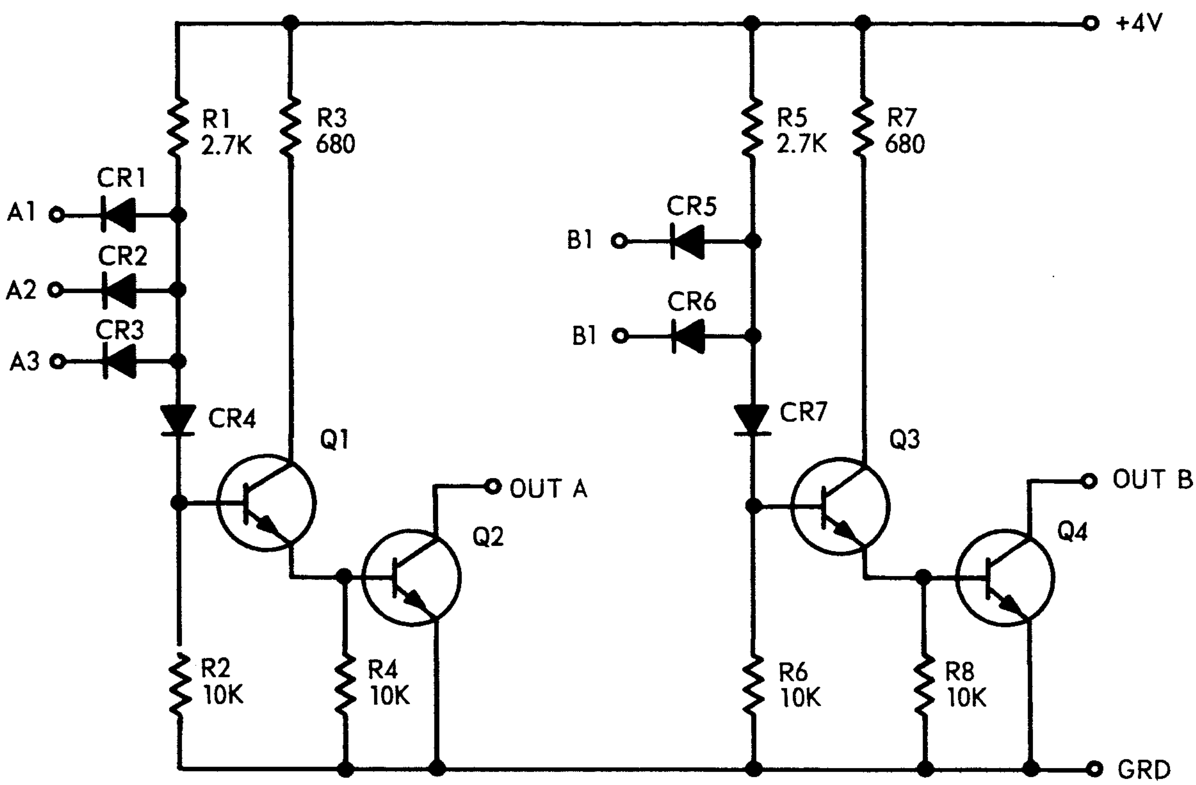
+4v CURRENT = 5MA MAX
3.2 MA MIN

ASSEMBLY NUMBER
R353286

4-3-2-1 NAND GATE
FANOUT = 6

2381-012

Figure 19. NAND Gate (R353286-1)



QTY	PART NO.	REF DESIG
7	479-0468-001	CR1 TO CR7
4	472-0153-001	Q1 TO Q4
2	R352869-73	R1, 5
4	R352869-87	R2, 4, 6, 8
2	R352869-59	R3, 7

DISSIPATION = 46 MW MAX

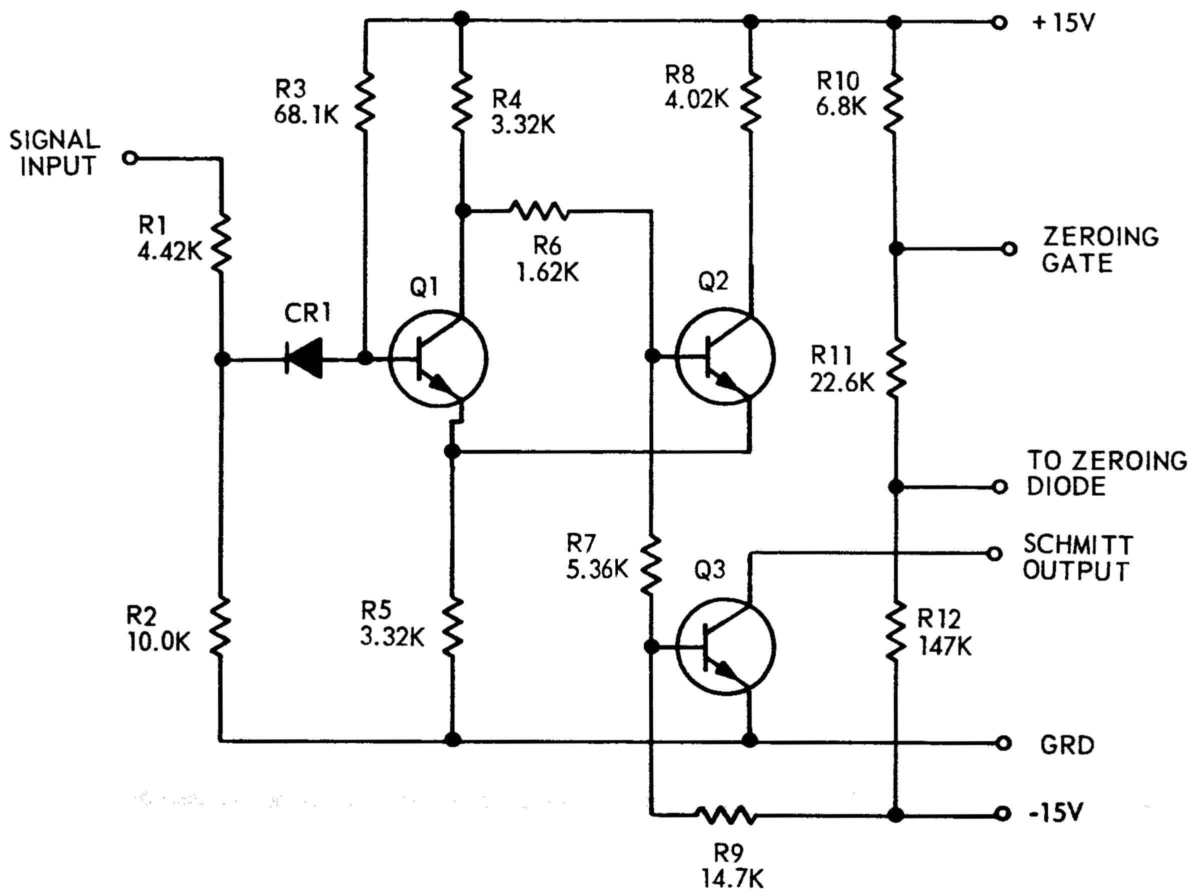
+ 4V CURRENT 11.4 MA MAX
2.5 MA MIN

3-2 POWER NAND GATE
50 MA SINK F.O. = 40

ASSEMBLY NUMBER
R353282

2381-008

Figure 20. Power NAND Gate (R353282-1)



QTY	PART NO.	REF. DESIG.
1	479-0468-001	CR-1
3	472-0153-001	Q1 TO Q3
1	R448219-263	R1
1	R448219-301	R2
1	R448219-381	R3
2	R448219-251	R4, R5
1	R448219-221	R6
1	R448219-271	R7
1	R448219-259	R8
1	R448219-317	R9
1	R448219-281	R10
1	R448219-335	R11
1	R448219-417	R12

ASSEMBLY NUMBER
R353288

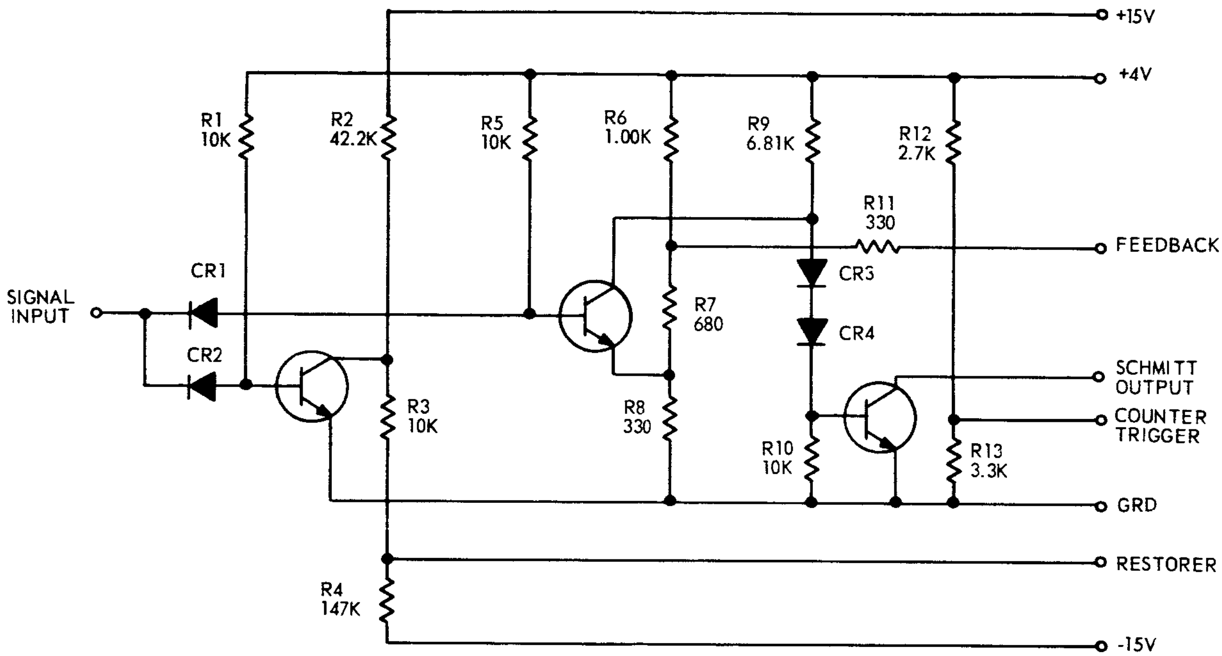
POWER DISS. = 57 MW MIN
71 MW MAX

	MAX	MIN
+15V	3.7 MA	2.8 MA
-15V	1.0 MA	0.8 MA

9.6 VOLT SCHMITT TRIGGER
AND ZEROING CONTROL

2381 014

Figure 21. 9.6-Volt Schmitt Trigger and Zeroing Control (R353288-1)



ASSEMBLY NUMBER
R353289

QTY	PART NO.	REF DESIG
4	479-0468-001	CR1 TO CR4
3	472-0153-001	Q1 TO Q3
4	R352869-87	R1, 3, 5, 10
1	R448219-363	R2
1	R448219-417	R4
1	R448219-201	R6
1	R352869-59	R7
2	R352869-51	R8, R11
1	R448219-281	R9
1	R352869-73	R12
1	R352869-75	R13

POWER DISSIPATION - 24 MW
+4V I MAX 5.6 MA
-15V I MIN 0.15 MA

D.C. RESTORER AND
0.4 VOLT SCHMITT TRIGGER

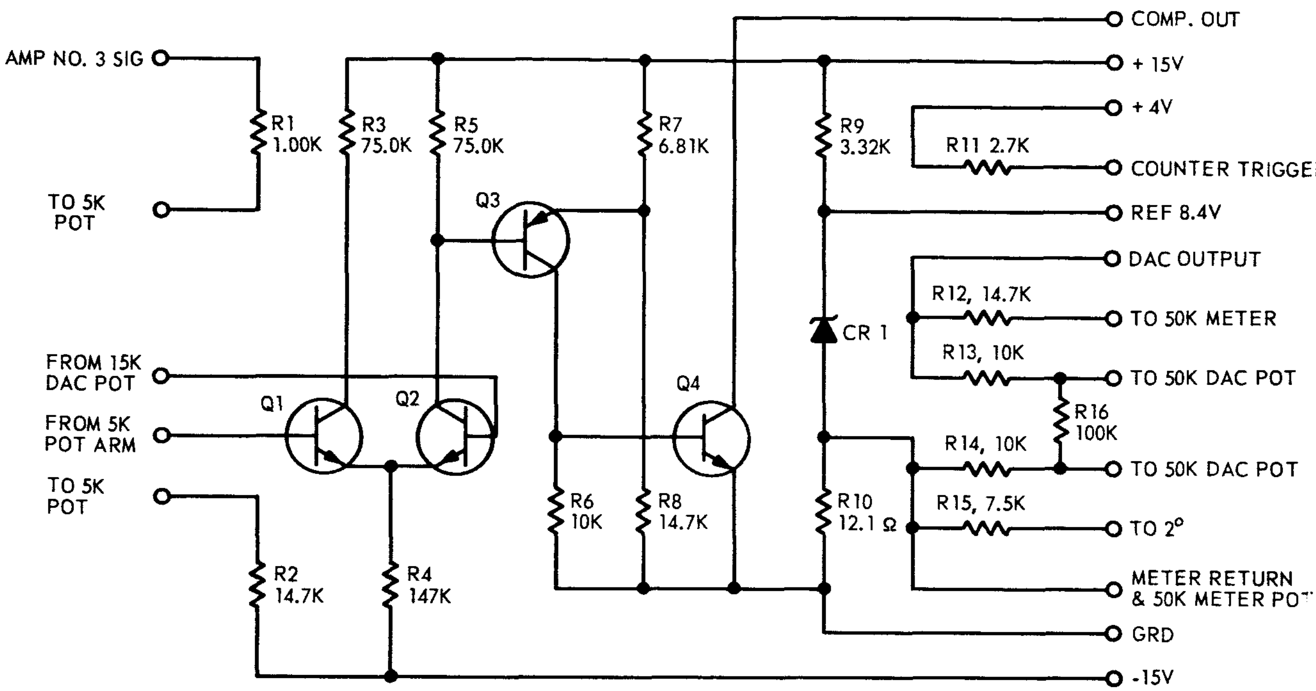
2381-015

Figure 22. 0.4-Volt Schmitt Trigger and DC Restorer (R353289-1)

Feedback for the Schmitt is provided by inverting the output with a one input NAND; this inverter is usually an integral part of a Schmitt Trigger circuit, but a standard external circuit is applicable. The circuit triggers off at 0.33 volt, which is the transistion that sets the gain change flip-flops. The function of the DC Restorer circuit is to prevent the Amplifier outputs from going negative. The Restorer output of this module forward biases a low-leakage diode whose cathode is connected to the input of the second high-impedance amplifier when the output is negative.

D.A.C. Comparator, figure 23, R353290-1, is composed of parts of several separate circuits. The principal circuit, the Comparator, monitors the amplifier signal No. 3 and the D.A.C. output and provides a logical zero output when the D.A.C. output is greater than the amplifier output. Q1 and Q2 are a differential amplifier with Q1 base connected to a voltage divider of 1.21-K and a 5-K potentiometer. This voltage divider is driven by amplifier signal No. 3. Q2 base is connected to the wiper of a 50-K potentiometer that "sees" a proportion of the D.A.C. output. Q3 is an amplifier that drives Q4, the output switching transistor. The 50-K and 5-K potentiometers are adjusted so that Q4 does not switch until the amplifier signal No. 3 is 5 volts. Within the module is also the 8.4-volt reference supply for the D.A.C. counters. This supply is referenced slightly (0.09 v) above ground by three 36.5-ohm resistors in parallel to compensate for the saturation collector voltage (0.09 v) of the D.A.C. counters.

Each D.A.C. Counter, figure 24, R353291-1, contains two resistors which form part of the D.A.C. ladder network. The counter itself is similar to Counter R353285 except that either collector voltage can rise no more than



QTY	PART NO.	CKT SYM
3	472-0153-001	Q1, 2, 4
1	472-0014-001	Q3
1	R448219-201	R1
2	R448219-317	R2, R8, R12
2	R448219-385	R3, R5
1	R448219-417	R4
1	R352869-87	R6
1	R448219-281	R7
1	R448219-251	R9
1	R448219-9	R10
1	R352869-73	R11
1	R448219-401	R16
2	R448219-301	R13, 14
1	R448219-285	R15
1	479-0011-001	CR1

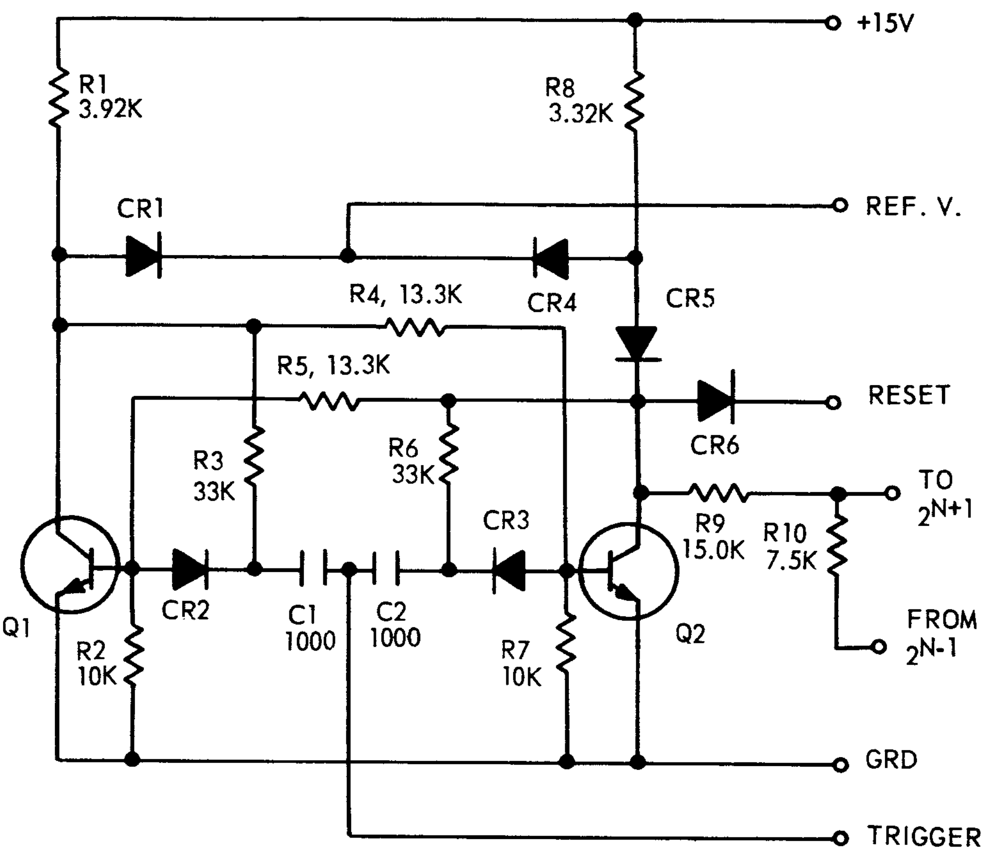
DISSIPATION 75MW. APPROX
+ 15K IMAX = 2.8 MA
- 15K IMAX = 1.1 MA

ASSEMBLY NUMBER
R353290

D.A.C. COMPARATOR

2381-016

Figure 23. DAC Comparator (R353290-1)



QTY	PART NO.	REF DESIG
2	R448218-66	C1, 2
6	479-0468-001	CR1 TO CR6
2	472-0153-001	Q1, Q2
1	R448219-258	R1
2	R352869-87	R2, R7
2	R352869-99	R3, R6
2	R448219-313	R4, R5
1	R448219-251	R8

DISSIPATION = 73.8 MIN 82.6 MAX
+15V I MAX 6.0 MA, I MIN = 5.6 MA

NOTE: CR4 AND CR5 ARE SELECTED SO THAT THE FORWARD DROPS ARE WITHIN 10 MV OF EACH OTHER AT 1.0 MA

ASSEMBLY NUMBER
R353291

D.A.C. COUNTER

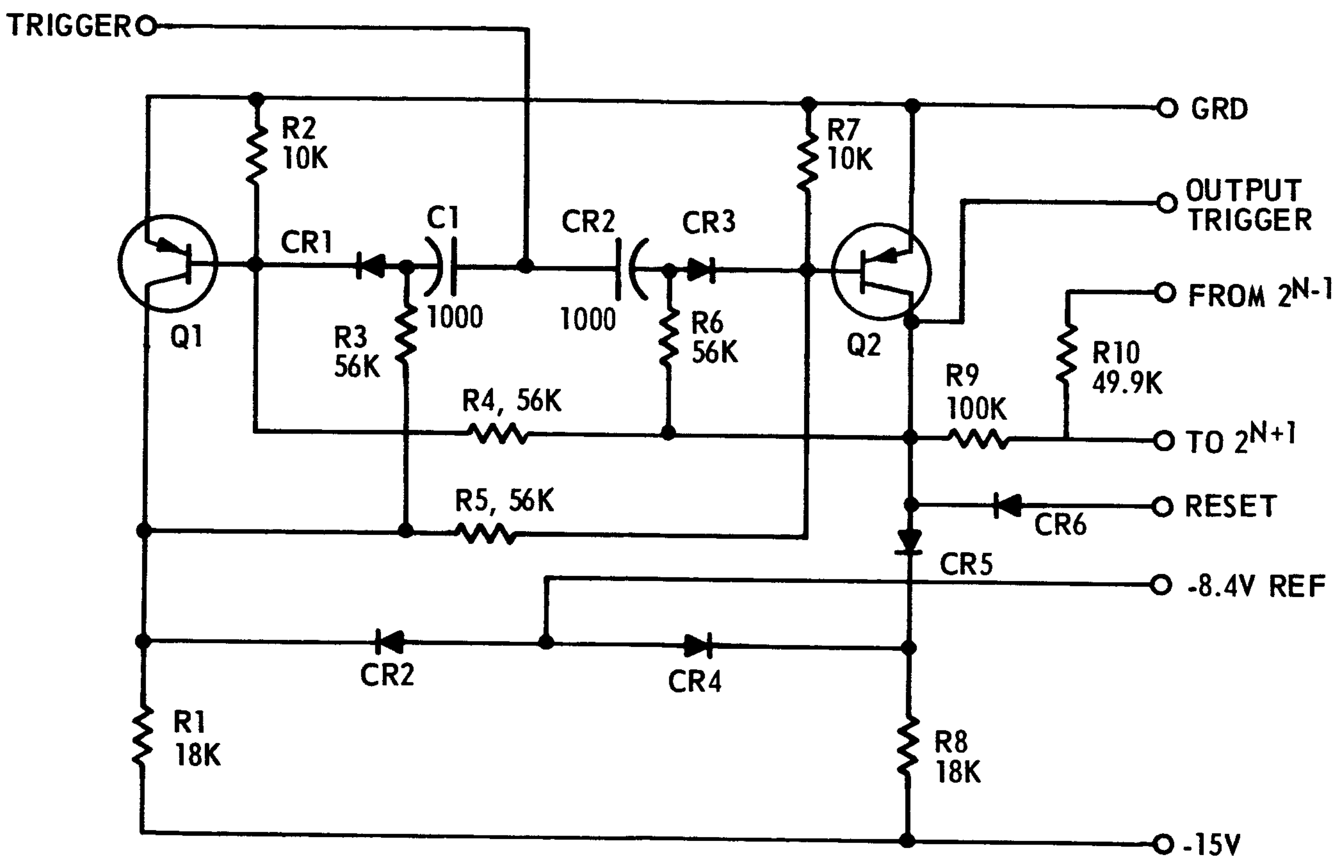
2381-017

Figure 24. DAC Counter (R353291-1)

the 8.4-volt reference. The Zeroing Counter, figure 25 (R353293-1) is similar to the DAC Counter except that PNP transistors are used.

The Level Converter and Output Network, figure 26, R353292-1, module contains four level converters and two output networks. The level converters impose on the two amplifier outputs specific information levels when the converters are activated. When a level converter input is grounded, its transistor is turned on applying 15 volts to the amplifier output through a resistor and series diode. The resistor determines the level desired on the output. The output network is a voltage divider on each amplifier that provides 500 ohms output to the two telemetry impedances.

The Automatic Zeroing Control Module, figure 27, R353294-1, which provides the necessary control for the zeroing Counters and their D.A.C. outputs, also provides a -8.4-volt reference supply for the Zeroing Counters. When the "not zeroing" ($\overline{\text{zeroing}}$) signal goes to ground, Q1 turns on and applies a reset ground level to the Zeroing Counters. At the same time, the zeroing signal goes positive allowing the 5.5-millisecond pulses through Q2 to the first Zeroing Counter. The output of the first high-impedance amplifier drops when the counters begin to count at one per second and the D.A.C. output begins to increase more negative. As the amplifier becomes negative (by one counter bit) CR4 inhibits further counting pulses. The C1, R2 network isolates the first high-impedance amplifier from the 1-microfarad capacitor in the system RC network. As the zeroing sequence is completed and the clamp is released from the input of the second high-impedance amplifier, the voltage change is transmitted back through the 1-microfarad capacitor to the first high-impedance amplifier upsetting its feedback



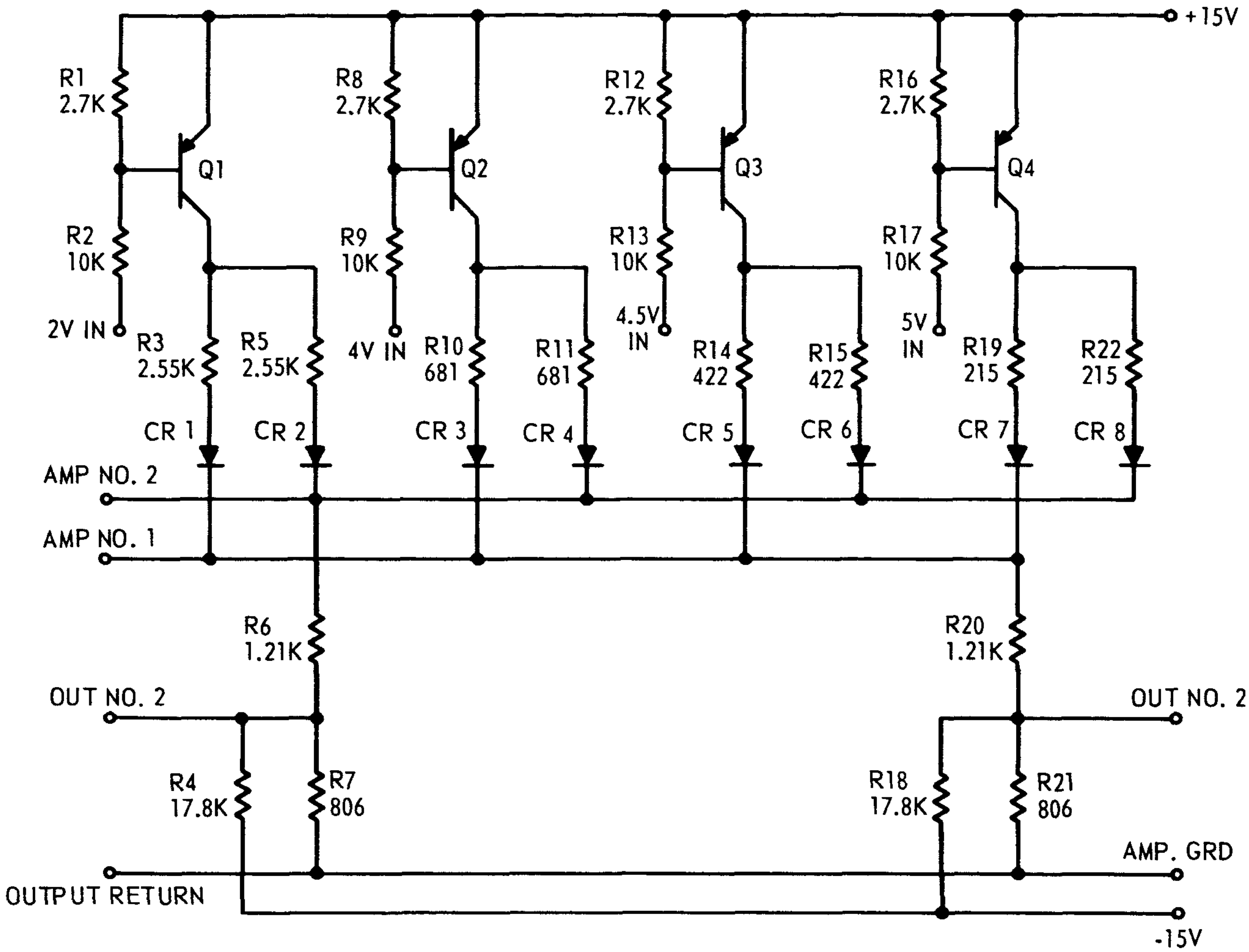
QTY	PART NO.	REF DESIG
2	472-0014-001	Q1, Q2
6	479-0468-001	CR1-CR6
2	R448218-66	C1, C2
2	R352869-93	R1, R8
2	R352869-87	R2, R7
4	R352869-105	R3-R6
1	R448219-401	R9
1	R448219-368	R10

POWER DISS. = 15.9 MW
-15V CURRENT = 1.18 MA

ASSEMBLY NUMBER
R353293

2381-019

Figure 25. Zeroing Counter (R353293-1)



QTY	PART NO	REF. DESIG.
8	479-0468-001	CR1 TO CR8
4	472-0014-001	Q1 TO Q4
4	R352869-73	R1, R8, R12, R16
4	R352869-87	R2, R9, R13, R17
2	R448219-240	R3, R5
2	R448219-325	R4, R18
2	R448219-209	R6, R20
2	R448219-188	R7, R21
2	R448219-181	R10, R11
2	R448219-161	R14, 15
2	R448219-133	R19, 22

	MAX	MIN
+15V	20.5MA	0
-15V	3.1MA	1.7MA

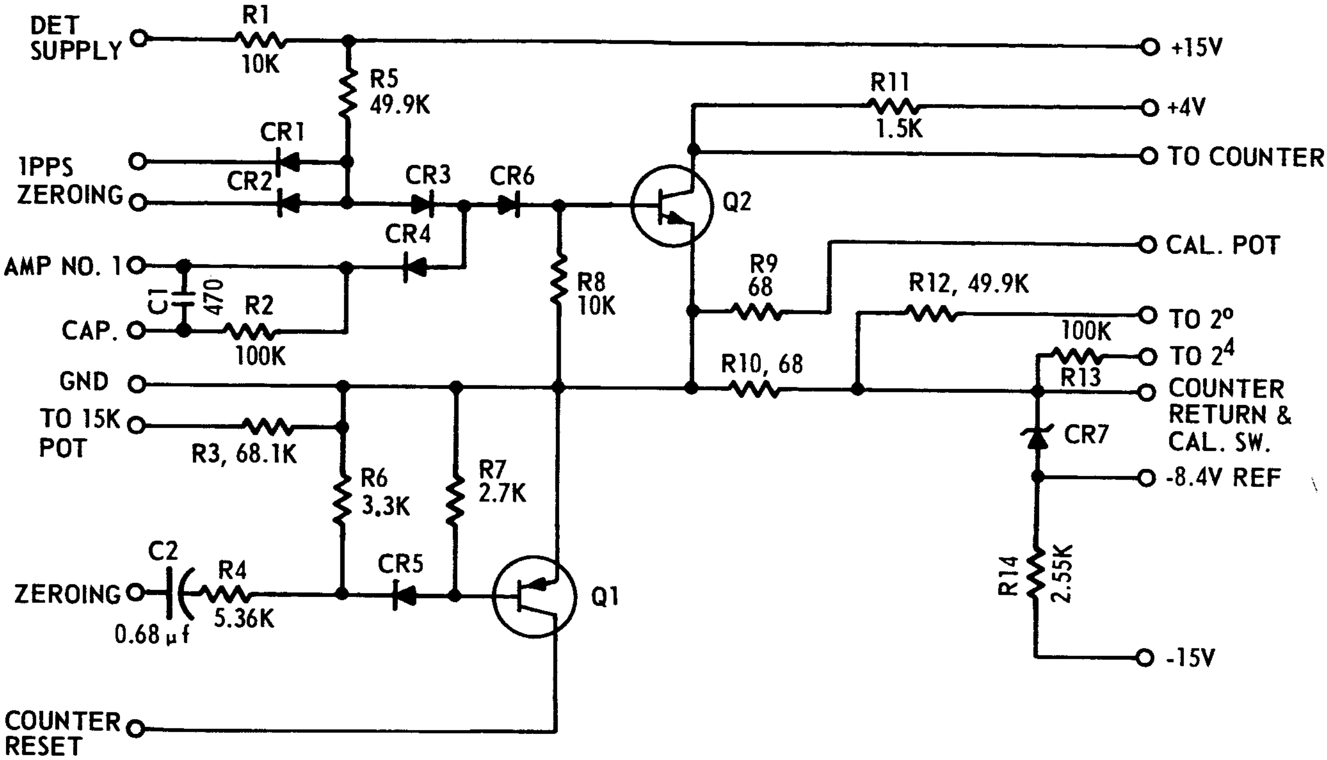
POWER DISSIPATION = 40 MW AVG.
300 MW MAX 1 SECOND

ASSEMBLY NUMBER
R353292

LEVEL CONVERTER
AND OUTPUT NETWORK

2381-018

Figure 26. Level Converter and Output Network (R353292-1)



QTY	PART NO.	REF DESIG.
1	R352869-67	R11
1	R448219-240	R14
1	441-0383-001	C1
6	479-0468-001	CR1-CR6
1	USN 1N3155	CR7
1	350D684X9035A2	C2
1	472-0153-001	Q2
1	472-0014-001	Q1
2	R352869-87	R1 & R8
1	R352869-99	R6
1	R352869-73	R7
2	R448219-368	R5 & R12
1	R448219-401	R2, R13
1	R448219-381	R3
1	R448219-271	R4
2	R352869-35	R9, R10

POWER DISSIPATION: 65MW

		MAX	MIN
CURRENT (MA)	+15V	1.0	0.72
	+ 4V	2.65	0
	- 15	3.75	3.26

ASSEMBLY NUMBER
R353294

2381-020

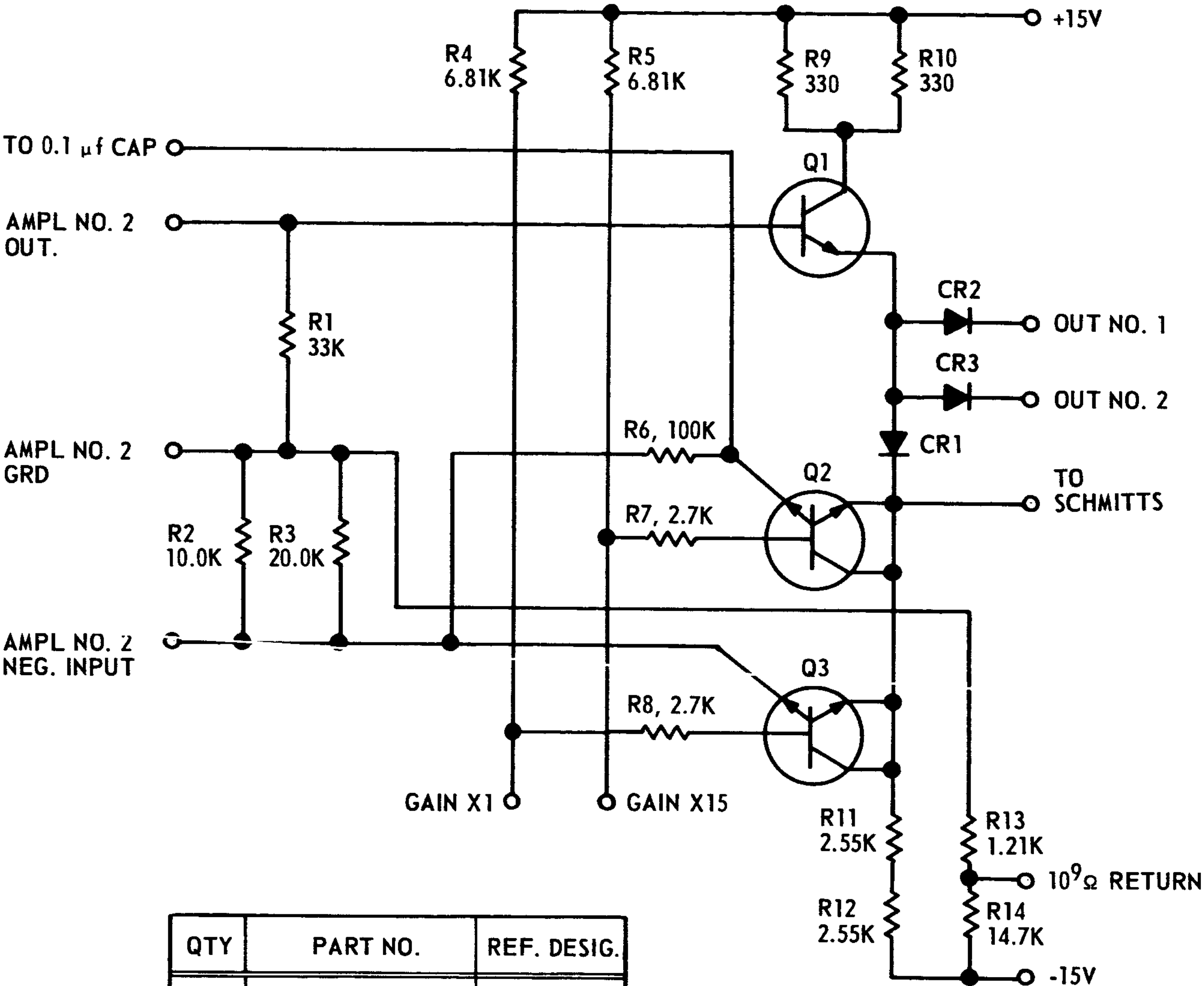
Figure 27. Automatic Zeroing Control (R353294-1)

network. The two 68-ohm resistors form part of the calibrate circuit. One 68-ohm resistor is parallel with the series combination of the other 68-ohm resistor and a 200-ohm potentiometer; this parallel network is connected between one side of the calibrate push button and ground. When the calibrate button is pushed, the reference is brought to ground which causes a small pulse of the input of the first high-impedance amplifier. The detector supply voltage comes from +15 volts through the 10-K resistor in this module.

The No. 2 Amplifier Control Module, figure 28, R353295-1, provides the necessary output conditioning and gain control, for the second high-impedance amplifier Q1 is an emitter follower, driven by the amplifier, that provides three separate outputs: Amplifier Signals No. 1, 2, and 3. Q2 and Q3 are double emitter transistors that switch in the feedback resistors from the Amplifier Signal No. 3 to the negative amplifier input on command from either or both the X1 and X15 gain signals.

The monostable single-shot multivibrator, figure 29 (R353287-1), is triggered by a positive-going input and initiates a positive pulse (logical 1) with a duration given by T (seconds) = 0.0165 C. C is the capacitance in microfarads of an externally connected capacitor.

Oven heat is obtained from four 10,000-ohm, 5-watt resistors connected in parallel. These resistors are mounted directly to the column-detector assembly. A bead thermistor monitors one of the resistors, and its varying resistance controls an amplifier which in turn provides bias to turn on an SCR regulating the current through the heater resistors. The heat control circuit is shown in figure 30 (R353296-1). In early tests it was noted

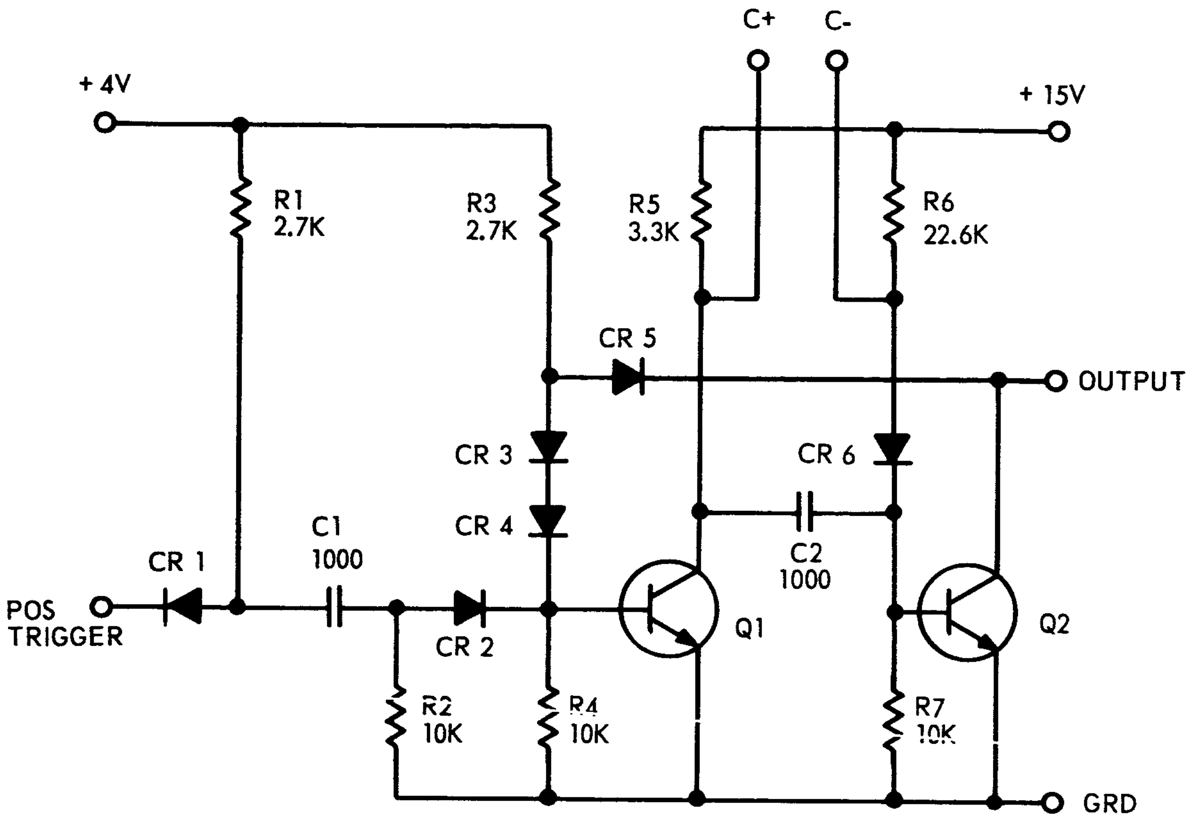


QTY	PART NO.	REF. DESIG.
3	479-0468-001	CR1-CR3
1	472-0153-001	Q1
2	3N74 TEXAS INST	Q2, Q3
1	R352869-99	R1
2	R352869-73	R7, R8
1	R448219-301	R2
1	R448219-330	R3
2	R448219-281	R4, R5
1	R448219-417	R14
2	R352869-51	R9, R10
2	R448219-240	R11, R12
1	R448219-209	R13
1	R448219-401	R6

2381-021

ASSEMBLY NUMBER
R353295

Figure 28. No. 2 Amplifier Control (R353295-1)



QTY	PART NO.	REF. DESIG.
6	479-0468-001	CR1 THRU 6
2	R448218-66	C1, 2
2	472-0153-001	Q1, 2
2	R352869-73	R1, 3
3	R352869-87	R2, 4, 7
1	R352869-75	R5
1	R448219-335	R6

ASSEMBLY NUMBER
R353287

POWER IN:

(19 + 91 X dv) MW

	IMAX	IMIN
+4V	2.5 MA	0.75 MA
+ 15V	5.9 MA	0.62 MA

PERIOD T = 0.0165C

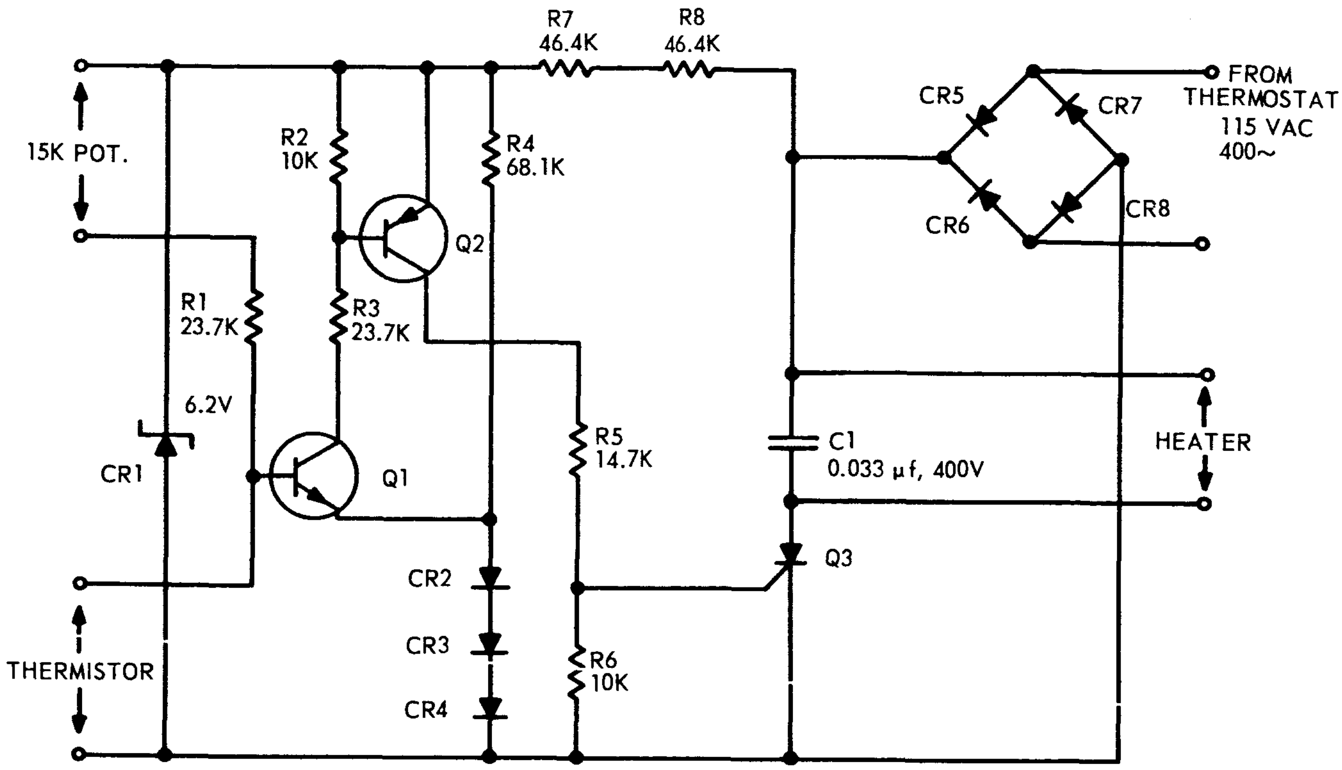
$$C = \frac{T}{0.0165}$$

WHERE T IS IN SEC.
C IS IN μ fd.

MULTIVIBRATOR,
SINGLE SHOT

2381-013

Figure 29. Monostable Single-Shot Multivibrator (R353287-1)



QTY	PART NO.	CKT. SYM.
1	479-0010-001	CR1
3	479-0468-001	CR2 TO CR4
4	479-0002-001	CR5 TO CR8
1	238P33394S13	C1
1	472-0153-001	Q1
1	472-0014-001	Q2
1	2N2328A	Q3
2	R448219-337	R1, R3
2	R352869-87	R2, R6
1	R448219-381	R4
1	R448219-317	R5
2	R448219-365	R7, R8

ASSEMBLY NUMBER
R353296

DISSIPATION: CONTROL ONLY

HEATER	
ON	OFF
285 MW	140 MW

MAX TOTAL DISSIPATION:

CONTROL + HEATER AT 119 VAC
= 5.5 WATTS

HEATER CONTROL

2381-022

Figure 30. Heater Control (R353296-1)

that heat cycling was occuring due to the response time characteristic of the thermistor. The thermistor originally used had a 25-second response time. This was replaced with a thermistor bead having a 2-second response time characteristic, resulting in a much improved proportional control.

Power Supply: The power supply used in the Apollo GCAS is an ac-to-dc converter employing high reliability components. The power supply is capable of operation with input voltage of 115 plus or minus 4 volts ac, 400 plus or minus 7 cps sine wave with 5% harmonic distortion.

Output voltages of the supply are as follows:

+ 15 volts dc at 75 to 160 ma

- 15 volts dc at 25 to 40 ma

+ 4 volts dc at 100 to 175 ma

Regulation of the power supply is within the limits indicated by the chart as follows:

Output	+ 15 vdc	- 15 vdc	+ 4 vdc
Regulation Load	± 15 mv	± 15 mv	± 0.1 v
Regulation Line	± 15 mv	± 15 mv	± 0.15 v
Regulation Temperature (-25° to 71°C)	± 0.1 v	± 0.1 v	± 0.2 v
Ripple (peak to peak)	2.5 mv	2.5 mv	0.2 v
Output Impedance (0 to 1 mc)	3 ohm max	1 ohm max	2 ohm max

The supply is housed in a package 3 by 2-1/2 by 3 inches and weighs about 3/4 pound; it delivers the output power with a 47% efficiency.

5. FUNCTIONAL CHARACTERISTICS

The prime purpose of this instrument is to quantitatively detect the presence of trace contaminants in spacecraft atmospheres. Towards this goal, a wide variety of possible spacecraft contaminants were tested during the breadboard stage of this program. The permanent gases, hydrogen, oxygen, nitrogen, methane, and carbon monoxide, were eluted from the molecular sieve column (column 1) in the usual order within 6 minutes. The retention times of compounds eluted from columns 2 and 3 are shown in table 4. These retention times were measured from the time oxygen was eluted in all cases. It may be seen that most of the compounds are eluted from both columns. Since the retention characteristics of the two columns are considerably different, this redundancy is expected to enhance the ease of peak identification.

Each of the units delivered during this project was subjected to a functional qualification test. Calibration mixtures used for these tests were prepared in standard 1A gas cylinders. These bottles were prepared for filling by evacuating, flushing with oxygen, evacuating, etc., for at least three times. Calculated quantities of liquid contaminants were then injected into the evacuated cylinders through a rubber septum. Small concentrations of gaseous contaminants were inserted from known volume containers. Large concentrations of gaseous contaminants were metered into the bottle until the calculated pressure increase was obtained. Oxygen was then used to pressurize the bottle to 200 psig. This technique thereby provided a calibration bottle with ppm levels of liquid and gaseous compounds, higher levels of some gases, and gross amounts of oxygen. The only

TABLE 4

RETENTION TIMES OF VARIOUS COMPOUNDS WITH AN AMINE-CARBOWAX-TEFLON COLUMN (COLUMN 2) AND A CARBOWAX-CHROMOSORB COLUMN (COLUMN 3)

Compound	Column 2	Column 3	Compound	Column 2	Column 3
Acetylene	0.2 min.	0.4 min	3-Methyl-2-Butanone	9.7	13.6
Freon 12	0.25	0.2	Isopropyl Alcohol	9.8	12.8
Ammonia	0.3	0	Ethanol	10.7	12.5
Freon 14	0.4	0.2	Propyl Acetate	10.7	17
Freon 22	0.5	1.0	Water	11.5	--
Carbon Dioxide	0.5	0.1			
Pentane	0.95	0.7	Acetyldehyde	11.5	3.1
Freon 11	1.3	1.45	Chloroform	13.15	23.2
Isoprene	1.6	1.9	Trichloroethylene	13.2	19.95
Methyl Mercaptan	2.1	2.4	Butyraldehyde	13.5	10.0
1,-1 Dichloroethylene	2.25	3.5	Ethylene Dichloride	13.8	34.0
Hexane	2.3	1.3	Isobutylacetate	15.6	22.4
Dimethyl Sulfide	2.4	4.0	p-Dioxane	17.1	35.7
Chloropropane	2.75	3.9	Methylisobutyl Ketone	17.5	22.5
Isopropyl Ether	2.78	2.1	Toluene	19.3	28.2
Acetone	3.0	6.2	Tetrachloroethylene	20.9	28.5
Carbon Disulfide		3.8	Propanol	24.8	25.2
Cyclohexane	4.9	3.7	Allyl Alcohol	28.6	40.5
Ethyl Acetate	5.3	9.7	o-Xylene	33.5	--
Methylene Chloride	5.5	12.6	Isobutyl Alcohol	37.0	28.0
Dimethyl Hydrazine	5.7	10.0	m-Xylene	41.8	53.7
Heptane	5.8 min	2.8 min	Butanol	51.3	
Butanone (MEK)	6.4	10.8	Monochlorobenzene	54.3	
Methyl Chloroform	7.0	8.6			
Methanol	7.3	10.3			
Ethyl Sulfide	8.6	11.3			
Benzene	9.6	14.8			

major difficulty encountered with this dilution technique has been adsorption of highly polar compounds on the container walls. This leads to low response values for certain compounds. All units were tested with two different calibration mixtures.

Functional test results for a typical instrument are shown in tables 5 and 6. These results were obtained with two different calibration mixtures. The sample pressure was adjusted to 2.5 psia for mixture A and to 5.0 psia for mixture B. Elution times for column 1 were measured from the time of injection. Elution times for columns 2 and 3 were measured from the oxygen peak. A cross comparison of these two tables with table 4 shows that the elution times are approximately but not exactly the same as obtained on the breadboard unit. These deviations are due to minor variations in operating temperature and gas flow. However, since all column systems used in the flight units as well as the breadboard unit are identical, the relative retention times will remain the same. Thus, if it is found that acetone is retained 20% longer on column 3 in unit 5 than indicated by table 4, all compounds eluted from column 3 in unit 5 will be eluted 20% later than shown in table 4.

It may be seen from tables 5 and 6 that contaminant concentrations as low as 50 ppm may be readily detected, even at sample pressures as low as 2.5 psia. The apparent sensitivity for highly polar compounds (notably methanol) and low volatility compounds is poorer than anticipated. This is probably due to adsorption or absorption of these compounds by the sample test apparatus or by the instrument itself.

TABLE 5

ANALYSIS OF MIXTURE A AT 2.5 psia

Compound	Concentration	Elution Time	Peak Height*
Column 1			
Hydrogen	49 ppm	1.1 min	0.5^3
Oxygen	99%	1.7	0.1^3
Nitrogen	371 ppm	---	----
Methane	46	3.1	0.1^3
Carbon Monoxide	19	---	----
Column 2			
Freon 11	300 ppm	1.9 min	0.55^2
Carbon dioxide	0.4%	4.2	1.25^2
Acetone	300 ppm	6.8	1.05
Cyclohexane	300	---	----
Methanol	500	---	----
Ethyl Sulfide	50	13.6	1.6
Water	---	17.5	0.55
Isobutyl Acetate	50	---	----
Toluene	50	---	----
Allyl Alcohol	300	---	----
Column 3			
Freon 11	300	1.65	0.85^2
Cyclohexane	300	3.95	0.50^2
Acetone	300	7.7	2.1
Ethyl Sulfide	50	---	----
Isobutyl Acetate	50	---	----
Toluene	50	---	----
Allyl Alcohol	300	---	----

*Those values with superscripts have been automatically attenuated. 15X attenuation has been employed for number 2, while 225X attenuation has been employed for number 3.

TABLE 6

ANALYSIS OF MIXTURE B AT 5.0 psia

Compound	Concentration	Elution Time	Peak Height*
<u>Column 1</u>			
Hydrogen	297 ppm	1.1 min	1.5^{3}
Oxygen	96%	1.6	0.45^{3}
Nitrogen	0.22%	2.3	0.85^{2}
Methane	276 ppm	3.9	0.12^{3}
Carbon Monoxide	115	5.7	0.13^{3}
<u>Column 2</u>			
Freon 11	50 ppm	1.95 min	0.25^{2}
Carbon Dioxide	2.0%	4.0	0.38^{3}
Acetone	50 ppm	---	----
Methanol	100	---	----
Ethyl sulfide	300	13.0	2.65
Water	---	17.5	0.25
Toluene	300	---	----
<u>Column 3</u>			
Freon 11	50 ppm	1.7 min	3.48
Acetone	50	7.9	0.8
Ethyl sulfide	300	13.1	0.55^{2}
Toluene	300	---	----

*Those values with superscripts have been automatically attenuated. 15X attenuation has been employed for number 2, while 225X attenuation has been employed for number 3.

6. RESPONSES TO APOLLO ENVIRONMENT

Two of the six GCAS units, produced under the specifications of this contract, were subjected to environmental tests designed to simulate conditions of the Apollo space craft environment during launch, flight and reentry. The two qualification units were also subjected to several storage and shipping environments. All environmental tests were conducted in accordance with NASA contract NAS 9-2518, test process number B169.02. Flight environment tests conducted were:

a. <u>Acceleration</u>: 7 g acceleration for 5 minutes in the x plane, 5.1 g acceleration for 5 minutes in the y and z plane, and 20 acceleration for 20 minutes in the x plane.

b. <u>Vibration - Random vibration</u>: 5-60 cps at .006 g^2/cps to 0.13 g^2/cps; 60-200 at 0.13 g^2/cps; and 200-2000 cps at 0.13 g^2/cps to 0.006 g^2/cps.

<u>Peak Vibration</u>: 5-15 cps at 0.3 g to 2.0 g; 15-100 cps from 2 g to 11 g; and 100-2000 cps at 11 g.

c. <u>Temperature</u>: Cycled from -15°F to +150°F. Temperature held at -15°F for 12 hours and at +150°F for 96 hours. A nonfunctional test at 200°F for 15 minutes was also conducted.

d. <u>E.M.I.</u>: Tested for radiation, conduction, & susceptibility.

e. <u>Temperature - Humidity</u>: 95% humidity over the temperature cycling from 35°F to 150°F for 14 days.

f. <u>Acoustics</u>: 4.7 cps to 9600 cps at levels from 122 db to 135 db (0 db = 0.0002 dynes/cm^2). GCAS noise output was measured over the range of 300 to 2000 cps with no noise generated in excess of 52 db.

g. <u>Hazardous gas</u>: subjected to explosive atmosphere.

h. <u>Earth Impact</u>: subjected to a shock pulse of 78 g for 11 milliseconds on all axes.

Storage and shipping tests performed, with the unit in a protective cover (except altitude), were:

a. Sand & dust.

b. Rain - 0.6 inches of simulated rain for 12 hours.

c. Salt Spray - 20% salt solution for 50 hours.

d. Altitude-simulated 35,000-ft altitude for 8 hours with temperature varying from $-20^{\circ}F$ to $+140^{\circ}F$.

e. Shock - 30-g level for 11 milliseconds.

No failures or degradation of performance occurred during or after the acceleration, temperature, altitude acoustics, hazardous gas, sand & dust, rain and shock tests.

Failures incurred during vibration tests resulted in improved mechanical designs. Virtually all spot welds were replaced with rivets. Foaming was added to the amplifier cavity. Wires were rerouted. Rubber shims were placed under the helium sphere mount and under the main chassis rails to lower the resonant frequency effects.

The initial E.M.I. tests resulted in failure during the conducted and radiated tests. (See table 7.) An RFI filter was designed and installed next to the heater control board. The results of the subsequent test are noted in table 8. All other E.M.I. tests were passed within specifications.

No failure of the unit was noted during and after the salt spray test. However, repeated failure occurred during the humidity test as a

TABLE 7

EMI TEST DATA, GCAS S/N 3

Frequency (Mcs)	Narrow Band Conducted		Broadband Conducted		Broadband Radiated	
	Specified DBMC	Measured DBMC	Specified DBMC	Measured DBMC	Specified DBMC	Measured DBMC
0.15	62.5	91	115	153	77	69
0.2	60.3	92	111	156	75	74
0.3	56.8	92	106	156	73	86
0.4	54.5	92	102	160	71.5	71
0.5	52.7	92	99.2	160	70.	78
0.6	51.2	92	96.5	160	70	82
0.7	50.0	91	94.6	155	69.8	85
0.8	48.8	89	93	150	69.8	85
1.0	47.0	86	90	145	-	-
1.2	45.5	89	87.5	150	69.0	73
1.5	43.8	71	84.7	137	-	-
1.8	42.4	71	82.2	144	-	-
2.4	40.8	70	81	139	68.5	68
3.0	38.2	69		134	68.1	68
4.0	35.8	64		123	-	-
4.8	34.5	64		119	-	-
6.4	34.0	64		116	67.3	76
8.0		62		113	67.0	52
9.6		60		111	66.9	52
12.0		46		104	-	-
15.0		30		95	-	-
19.0		29		93	66.1	47
21.0		29		93	-	-
23.0		29		93	-	-
25.0	34.0	29	81	92	-	-
30.0	-	-			47.0	47
60.0	-	-			51.2	37.6
120.0	-	-			52.5	35.1

TABLE 8

EMI TEST DATA, GCAS S/N 5 (With Filter)

Frequency (Mcs)	Narrow Band Conducted		Broadband Conducted		Broadband Radiated	
	Specified DBMC	Measured DBMC	Specified DBMC	Measured DBMC	Specified DBMC	Measured DBMC
0.15	62.5	29	115	92	77	30
0.2	60.3	36	111	94	75	< 30
0.3	56.8		106	99	73	
0.4	54.5	36	102	99	71.5	
0.5	52.7		99.2	83	70	
0.6	51.2	34	96.5	76	70	
0.7	50.0		94.6	76	69.8	
0.8	48.8		93	77	69.8	
1.0	47.0		90	74		
1.2	45.5	28	87.5	77	69.0	
1.5	43.8		84.7	76		
1.8	42.4		82.2	75		
2.4	40.8	31	81	75	68.5	
3.0	38.2			74	68.1	
4.0	35.8	25		75		
4.8	34.5			73		
6.4	34.0	20		68	67.3	
8.0				70	67.0	
9.6		13		-	66.9	
12.0				64	-	
19.0		< 0		59	66.1	
25.0	34.0	< 0	81	58		
30.0	-		-		47.0	< 30

result of corrosion activated by salts deposits. The salts deposits were believed to have accrued during the salt spray test. The affected electronic boards were cleaned in water and dipped in humiseal.

No electronic components failed as a direct result of any environmental test.

7. SUMMARY

It has been Melpar's privilege to perform under this contract with the Manned Spacecraft Center on the fabrication of flight qualified gas chromatography systems for use on the Apollo missions. In this report an attempt has been made to cover certain fundamentals of the system. This report on the other hand is not all-inclusive in the sense that it is redundant as far as previous information submitted to NASA, Houston, is concerned. For instance, no attempt has been made to significantly overlap the information contained in the instruction manuals which are submitted with each delivered unit. Nor has an attempt been made to go into the details of the environmental test results and their interpretation. These data are to be given in a separate package by 1 May 1966. Engineering drawings and acceptance test data also accompany each of the six units delivered.

Melpar believes that under this contract it definitely advanced the state of the art in arriving at a multipurpose, self-contained gas chromatographic system which meets the performance specifications delineated by the Manned Spacecraft Center. In addition, the unit is flight qualified and does conform to NASA Specifications NPC 200-2 and NPC 200-3. Specific components and circuitry that have been developed under this program include (a) a three-in-one cross-section ionization detector, (b) detector switching circuitry, (c) automatic zeroing circuitry for amplifiers based on a digitized output, (d) two steps of automatic gain change circuitry, (e) an oxygen hold circuit, (f) reliable sample injection valves, and (g) an effective solid-state programmer for controlling the steps in the repetitive analyses. Each of these components is discussed in more detail in the proper sections of this report.

Melpar has appreciated this opportunity to work with NASA personnel on this Apollo Gas Chromatography program. It wishes to acknowledge the assistance of Mr. John Lem, NASA Project Officer, in defining desired functions of the system as well as giving definition to spacecraft interface problems.